ANSI C16.37-1971

IEEE Std 167-1966

Reaffirmed 1971

(Revision of 43 IRE 9 S1)

Test Procedure

for

FACSIMILE

Approved March 8, 1971

American National Standards Institute

(Effective June 29, 1966)

IEEE No. 167

PUBLISHED BY

345 EAST 47 STREET, NEW YORK, N. Y. 10017

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

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FOREWORD

These test procedures are to bring up to date the IRE "Standards on Facsimile—Temporary Test Standards—1943" (43 IRE 9.S1). In part there has been new experience and technological advance since then. But it has also been noted that that document could, to advantage, be made more complete and cover a wider range of tests. An important objective has therefore been to make the new test procedures more comprehensive, to cover tests for determining most of the measurable quantities that were defined in IRE Standards on Facsimile: Definitions of Terms (56 IRE 9.S1, ASA C16.30-1957) now IEEE No. 168. The scope, in part, has been derived from facsimile equipment designed to operate over a telephone frequency bandwidth, but the tests are described in a general way, to make them utilizable over wider bandwidths as far as possible.

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INTRODUCTION

Facsimile is defined as the process, or the result of the process, by which fixed graphic material including pictures or images is scanned and the information converted into signal waves which are used either locally or remotely to produce, in record form, a likeness (facsimile) of the subject copy.

The purpose of this Test Procedure is to specify uniform methods of measuring performance characteristics of facsimile systems. Underlying theory is generally omitted as this material is available from other sources, but a brief discussion is given of the principles involved for each measurement. Where possible the measurements call for the use of the IEEE Facsimile Test Chart, which provides a convenient high-quality testing tool. The CCITT has also developed a test chart which is in use in many countries throughout the world. The general measuring procedures are outlined here and the factors which affect the accuracy of the results are discussed along with methods of presenting the results. Not all of the tests described will be significant for all types of facsimile equipment. The user must select the tests which are relevant for the type of equipment used and the intended application.

The facsimile art differs from most others in that a permanent graphic record is made of each transmission. In part, for this reason, there has not always been great urgency to develop precise measuring methods. Even where an exact measuring procedure is available, in actual use the frequent technique is apt to be a mere examination and visual estimate of the final received copy. This is quite advantageous in regard to the time taken for the tests. It does suffer, of course, from not being as reproducible as an objective test.

In the procedures which are outlined herewith, there are occasions where it is deemed desirable to describe both procedures. A good illustration of this lies in the testing for Noise (section 3.4). The more usual test for this is by visual inspection of a picture—in a more specialized case, a flat "screen" transmission may be used. This is described. However, on occasion a more objective test, also described, is available using a meter. Not all observers will agree on the visual test, especially with the general picture, but the meter reading will be independent of the operator. Parallels to this situation occur often.

In order to make clear, where several possible tests are described, which is to be considered the fundamental one, this has been designated "BASIC TEST." In most cases this uses the most objective procedure. There are, however, a few situations where a more subjective test is so much more significant that it has been selected. The basic test is not necessarily the most common one used in the art, nor even the most desirable in any given case, for the same types of reasons that in physical measurements one only very rarely has recourse to a primary standard. Therefore, in order not to give a wrong impression, the term "preferred test" has been avoided. The order of presentation of alternative tests has been chosen for most apt description, and no effort has been made to place the basic test in any uniform location.

Throughout, the testing procedures have been based as far as possible upon the definitions for the quantities being measured, as set forth in the 1956 IRE standard, "IRE Standards on Facsimile: Definitions of Terms, 1956" (IEEE 168). However there are cases where the definition is so idealized that the measurement would not be significant. In such cases a practical interpretation has been given to the terms, to conform to current usage. A typical example of this occurs in the test for Maximum Modulating Frequency (1.5.3). In other cases it has been found desirable to extend the definitions, as in the tests for Scanner—Overlap and Underlap Y (2.2.1).

It is recognized that in some cases a concept can lose some of its exact significance and even become meaningless if the component quantities upon which the concept is based do not permit it or are too irregular. This is somewhat analogous to asking, "What is the width of the Atlantic Ocean?" In such cases the procedure has been selected and described in a fashion to be utilizable as far as, and sometimes even somewhat beyond, the point where the quantity being measured has physical meaning. However no tortuous efforts have been made to push a mathematical concept to an extreme logical end. An illustration is given in the test procedures for measuring Recorded Spot X Dimension (1.2.1.2.1).

The simplest complete facsimile system consists of a transmitter, a communications facility or path, and a receiver. There are many occasions where essentially the same property is to be tested in the three places. An example of this is for the Halftone Characteristics (1.4). In such cases it is desirable, when making a measurement, to state specifically where, in the whole system, the input is considered to be, and where the measurement is being made. The units of measurement are necessarily different for the graphic material at the two ends and for the electric signal in the middle. These units therefore need in each case to be specified explicitly. Subsidiary cases of this problem occur when measuring either the transmitter or receiver, because the signal can undergo many electric transformations between the line and the graphic material.

The facsimile art is growing in many directions, such as toward use of wider frequency bands and toward use in satellite systems. An effort has been made to choose testing methods which are as general as possible so that they will remain applicable with advances in the state of the art. However, one must be resigned to the likelihood of cases where any given procedure can become obsolete for some newly developing system, and to the need for reviewing the testing methods from time to time.

1. EQUIPMENT SPECIFICATIONS

1.1 *Dimensional and Speed Specification of Copy*

1.1.1 *Scanning Line Length*

If the scanner is of the rotating-drum type, the scanning line length is the circumference of the drum including the effect of thickness of copy.

BASIC TEST: If the scanning process is linear, that is, if the scanning spot speed is constant over the subject copy, the scanning line length may be measured by transmitting a portion of the IEEE test chart.

The receiver is de-phased so that the edges of the subject copy image appear in the middle of the record sheet. The reproduction of pattern 19 of the IEEE test chart, including its horizontal line, is observed, the point (a) at which the horizontal line starts just after the dead sector or clamp bar interval, is noted; as well as the point (b) at which the line ends, just before the dead sector (see Figure 1).

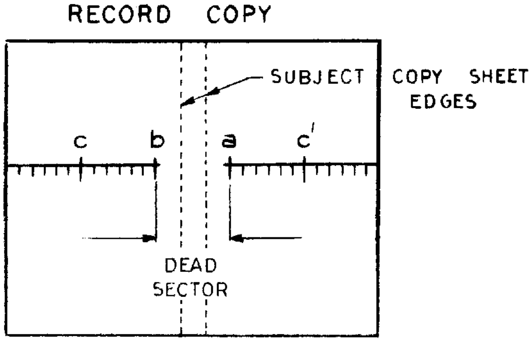

FIGURE 1

A third point (c) is marked on the line at a distance (a-b) back from (b) and its position on the line is noted (or a point (c′) is marked a distance (a-b) forward from (a), and its position noted).

The points (a, b, and c or c′) are transferred back to the chart being used as subject copy, as in Figure 2. Point (d) is marked on an extension of the line at a distance (c-b) beyond

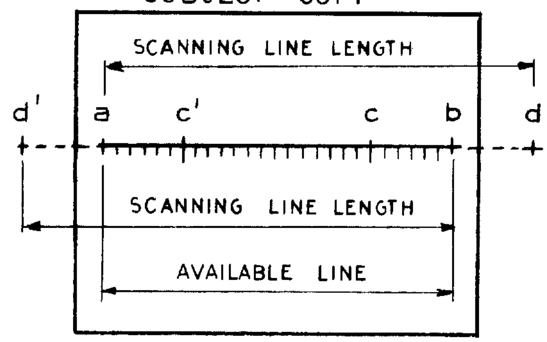

FIGURE 2

(b) (this may end off the sheet, which necessitates pasting an adjacent sheet). Or point (d′) may be marked on an extension in the reverse direction, at a distance (a-c′) ahead of (a). Then the distance (a-d), or (d′-b) on the subject copy is the scanning line length. If both points (d and d′) are transferred, and (a-d) does not equal (d′-b), this is an indication of nonlinearity in the scanning.

BASIC TEST: For a measurement of the corresponding recorder line length, a second transmission is made, not de-phased. The points from the first recording are transferred to this second recording instead of to the subject copy. The distances (a-d) and (d′-b) will be the recording line length.

Where the scanning is not linear the scanning line length loses some of its meaning, but a scanning line duration may be obtained from a suitable time representation of the electric signal on a linear time base oscilloscope. The scanner is set up to scan the horizontal line of

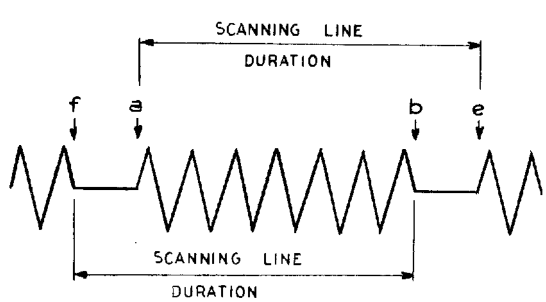

FIGURE 3

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pattern 19 on the chart continuously. The amplitude-modulated signal appears as shown in Figure 3. The distance (a-e) or (f-b) is proportional to the scanning line duration. This measurement can be obtained from a calibration of the oscilloscope trace.

1.1.2 *Available Line—Useful Line*

1.1.2.1 *Scanner*

BASIC TEST: The available line of the scanner may be measured by substantially the same process as the Scanning Line Length (see 1.1.1). The receiver is dephased so that the edges of the subject copy image appear in the middle of the record sheet (as in Figure 1). The reproduction of pattern 19 on the chart, including its horizontal line, is observed. The point at which the horizontal line starts just after the dead sector is noted, as well as the point at which the line ends, just before the dead sector.

These points (a) and (b) are transferred back to the chart being used as subject copy. The distance between them is the available line of the scanner (see Figure 2).

1.1.2.2 *Recorder*

BASIC TEST: The available line of the recorder may be measured by recording a steady signal on the record sheet of the recorder in question. The measured length of the horizontal lines on the record sheet is the available line of the recorder.

NOTE 1: The actual useful copy width is the maximum width of copy which can be handled by a facsimile system. In a system which does not incorporate reduction or enlargement the shorter available line length (as limited by scanner or recorder) minus the phasing deviation and skew equals the actual useful copy width.

NOTE 2: The subject copy sheet width usually is larger than the useful copy width. In some equipments (i.e. clamp bar-drum type scanners), the sheet width dimension must be held to a fairly close tolerance while in others there is only a maximum width limitation.

1.1.3 *Usable Length of Copy in Noncontinuous Components*

There are two distinct quantities which this measurement covers:

(a) Maximum and minimum length of subject copy accepted by the scanner and record sheet by the recorder.

(b) Maximum length of intelligence on the subject copy, which can be scanned at the transmitter; or on the record sheet, which can be recorded at the receiver.

BASIC TEST (a): The maximum and minimum lengths of subject copy and the maximum length of record sheet may be determined merely by placing sheets of these limiting dimensions into the machines, then measuring them.

In the simpler cases the maximum length of intelligence on the subject copy can be determined by placing a subject copy in the transmitter and noting the first and last points at which picture signals are produced, then measuring the distance between them on the subject copy.

Also, in the simpler cases the maximum length of intelligence on the record sheet may be determined by noting the first and last points at which picture signals can be recorded, then measuring the distance between them on the record sheet.

Where these operations are not feasible, or where the measurement is desired over a complete system, the following procedure may be used:

BASIC TEST (b): Place into the transmitter subject copy with message information extending to or beyond the expected scanning limits of the transmitter. Record a copy, examine it and note starting and ending limits of the recorded copy on the subject copy.

In certain cases it may be necessary to send the subject copy out of frame, at the top and again at the bottom, in order to distinguish the limitations imposed individually by the transmitter or the receiver. The specific method required to accomplish this will depend upon the individual system. The net length may be measured after transferring the critical points on the appropriate copy.

1.1.4 *Stroke Speed*

The measurement of stroke speed takes on quite different aspects according to the use to be made of the results. For successful compatible operation, free of skew, the stroke speeds of scanner and recorder must match to quite a high degree of accuracy (see 1.7 Compatibility between Transmitter and Receiver, and 2.3.1 Skew, where an accuracy figure of 1 part in 10^5 is mentioned illustratively; and higher accuracy may be needed in more exacting applications).

In some systems the apparatus alone need meet only a nominal figure of stroke speed, and the exact speed during operation is set by some kind of transmitted signal. Such signals can be a line start pulse (as used in broadcast television), or a single-frequency synchronizing wave which can be multiplexed on the picture signal or sent separately (a case of which is the use of a common 60-cycle-per-second power wave between sender and receiver), or other signals linking the two locations. In such cases the measurement of stroke speed on scanner and recorder separately need only be approximate, and within the tolerance range over which the equipment can be driven by the signal.

In other systems the scanner and recorder are driven by independent local clocks (or constant-frequency oscillators), and the two keep in step by virtue of the constancy of these oscillators.

If the speed at which a machine is designed to be driven is unknown, it can be tried with a variable-frequency oscillator drive to find the range of speeds at which it can respond. Or, if it can run free at its approximate design speed without its clock, this speed can be measured in the nominal fashion mentioned above.

However, scanners and recorders, each with and operated by their individual drive clocks, need to have their stroke speeds measured to a very much higher standard of accuracy if it is then expected that they will be shipped out to the field and made to work compatibly on the basis of the measurements. The accuracy that is required in this case then follows the usual principle that it must be illustratively something like an order of magnitude better than the performance requirement for the machines in operation.

Since the measurement is one of frequency it involves essentially a comparison of the unknown with a standard frequency. For some years a standard of frequency has been maintained by the National Bureau of Standards at Boulder, Colorado (USFS).[1] This has been broadcast by radio stations WWV (Greenbelt, Md.) and WWVH (Maui, Hawaii), also by WWVB and WWVL. Other reference standards are broadcast by NBA, NPG, NPM, NSS, and several other countries.

These are broadcast with high accuracy (in the case of WWV to something like 150 parts in 10^{10}) but reception is impaired by motions of reflecting layers of the ionosphere. Thus among other precautions it is necessary to select quiet periods for the ionosphere, when this motion is known to be small. Low-frequency stations transmitting at frequencies below about 25 kilocycles per second are generally free of doppler effect due to ionospheric shift.

The problem is under continuing study, and recommendations are subject to regularly announced notices by the National Bureau of Standards in appropriate technical publications such as the Proceedings of the IEEE.[2]

Some commercial organizations manufacture equipment to make the comparison convenient.[3] Also in recent years commercial standard oscillators have become available whose frequencies are likely to be more stable than standard frequency transmissions received via the ionosphere.

There are essentially two types of measurement which can be made. One is a measurement of the frequency of the local facsimile oscillator which is used with the system. This is translated into the stroke speed, with a knowledge of the number of poles in the drive motor, the ratio of any gearing between the motor and scanner or recorder head, the number of scanner or recorder heads, and possibly other pertinent facts, according to the mechanism.

The other type of measurement is one of the time interval between successive scanning or recording strokes. This is the reciprocal of the stroke frequency or speed. For the accurate measurement of stroke frequency, this is in general the most convenient, and it is the recommended, method. There are various possible procedures which can be used, depending upon the apparatus available and what part of the standard frequency signal is used.

Possibly the simplest, and the recommended, procedure is to use the pulse modulation of the standard, at one second (or other) intervals and record these on a facsimile receiver together with stroke indicating pulses from the apparatus under test.

An alternative is to use the continuous wave modulation of the standard signal and count cycles with an electronic counter, over intervals gated by stroke indicating pulses.

The applications to facsimile transmitters and receivers, respectively for tests, are described in somewhat more detail later.

1.1.4.1 *Scanning-Line Frequency*

For a conventional rotary drum transmitter this is equal to the drum speed in revolutions per minute. It can therefore be measured by the use of a suitable tachometer on the drum shaft. In most cases this will have only sufficient accuracy for a nominal measurement as discussed in the preceding section.

It is also possible, again as mentioned in the preceding section (and where the operation is not start-stop), to determine the scanning-line frequency from the input drive frequency to the motor, with a knowledge of the number of pole pieces, gear geometry, etc. The accuracy obtained here depends upon the accuracy with which the drive frequency is known or determined. General methods for measurement of such a frequency, in comparison with a standard, have been described in the literature,[4, 5, 6] and will not be repeated here.

BASIC TEST: Where the high accuracy is required, to apply the recommended method which uses standard one-second (or other) pulses, a receiver and its recorder are needed which can record the standard WWV or other signals. This would require a radio receiver giving a signal in the audio output which can be accepted by the facsimile receiver. On the transmitter scanner to be tested is placed subject copy with a single sharp line perpendicular to the scanning line (the scanner feed may also be disabled), and the output signal is superposed on that from the standard source.

With continued reception the record shows two or more lines crossing the scanning lines, one set of lines from the standard and another from the machine under test. For example, if the machine has 90 strokes per minute (and the recorder also) this would give 1½ strokes per WWV one-second pulse and that record would appear as two dotted lines. The deviation from parallelism between the standard lines and the test lines gives a measure of the scanner timing deviation from that of the standard.

The longer the duration of the record the higher can be the accuracy of measurement. For highest accuracy the recording and line feed processes of the receiver can be stopped after an initial recording, and resumed after a considerable length of time (for example an hour). This greatly enhances the displacement which results from lack of parallelism, and improves the ease and accuracy of measurement.

The detailed application of the test requires a numerical calculation of the significance of a lack of parallelism between the traces. This will naturally vary with the specific speeds and standard signals involved. But it is assumed that when the traces come out parallel, the stroke speed can be exactly determined from the standard signal used. The problem is then to compute, for the cases where the traces are not parallel, the numerical correction to this stroke speed, indicated by a measured departure from parallelism. In a general way it can be said that with

M = scanning lines per minute

N = standard timing pulses per minute

and, if the relationship holds that

$$m/M = n/N \tag{1}$$

where m and n are the smallest integers for which this holds, then the timing signal produces a pattern of n dotted lines on the record sheet, the dots being m scanning lines apart.

The pattern appearance is subjective, and it will appear to the eye as described, only if m and n are small. If the actual ratio of M to N differs only slightly from such a simple case, the simple pattern will still show, but it will be skewed. The skewed pattern can be exactly represented by

$$(m + e)/(M + u) = n/N \tag{2}$$

Here the small change in M from the simple case is expressed by $M+u$, and the corresponding small change in m to maintain the equality is expressed by $m+e$. For the subjective impression to remain u must be small compared to M, and e must be significantly smaller than ½.

From equation (2) the quantity u, which is the departure of the scanning line frequency from M (that gives the simple non-skewed pattern) is

$$u = (mN - Mn + eN)/n \tag{3}$$

From equation (1) $mN = Mn$

$$\text{Thus} \quad u = eN/n \tag{4}$$

The quantity e may be measured from the relative slope S of the timing pulse record with respect to the record of the signal from the scanner under test. From this e is computed as

$$e = SmW/L \tag{5}$$

where W = nominal scanning line width (see 1.2.2)

L = scanning line length (see 1.1.1)

From these one obtains the frequency departure u as

$$u = SN\,(m/n)\,(W/L) \tag{6}$$

An illustrative case (noted several paragraphs previously) is shown in Figure 4. The records of the scanner signal A and timing signal B are for the case where

M = 90 lines per minute (scanner and recorder)

N = 60 pulses per minute

m = 3

n = 2

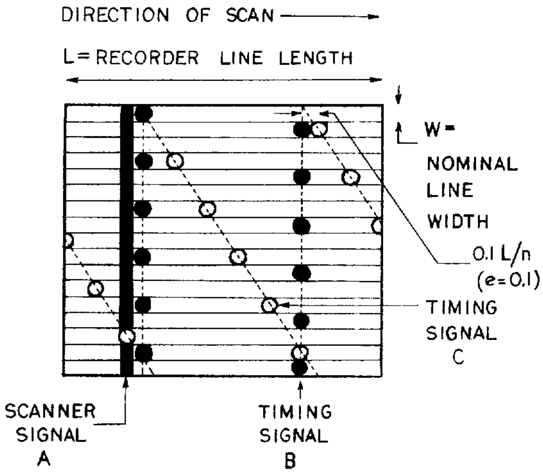

FIGURE 4

Here the scanner signal records as a single solid line perpendicular to the scanning lines. The timing pulses record as two dotted lines with the dots coming every 3 scanning lines. The dotted lines are parallel to the solid line, namely $e = 0$, and M is exactly 90 lines per minute.

The case is also shown where the timing signal C (in hollow dots) forms lines which are slanted with respect to the scanner signal. The case illustrated shows a relative slope of ½ scanning line length per 15 scanning line widths, namely

$$S = (1/30)(L/W) \tag{7}$$

In this case, from equation (5)

$$e = 1/30\ (L/W)(3)(W/L)$$
$$= 1/10 \tag{8}$$

In this case, from equation (6), the frequency difference u (from M) is

$$u = 1/30\ (L/W)(60)(3/2)(W/L)$$
$$= 3 \text{ lines per minute} \tag{9}$$

This illustration then shows the scanner (and also the recorder) operating at 93 lines per minute, as measured from a timing pulse of one per second (or 60 per minute). If the recorder operated at another speed than the 93 lines per minute of the scanner, both sets of lines A and C would be slanted somewhat differently, but the relative slope S between A and C would remain the same.

The alternative procedure which has been mentioned may be applied by using the same subject copy described above for the transmitter under test, and arranging for the successive output pulses (one stroke duration apart) alternatively to open and close a gate. The standard frequency signal cycles go through the gate, and a counter counts their number passing through, to measure the stroke duration. Repeated operation can give an average figure, with higher accuracy than the single test. Commercial apparatus is available for this operation.

1.1.4.2 *Recording-Line Frequency*

For a drum-type or helix-type machine, this can be measured with a tachometer as in the case of the scanner. For a multistyli belt-type recorder a tachometer on the drive pulley shaft will give a reading which may be multiplied by the ratio of the circumference of the pulley to the scanning line length to determine the recording-line frequency. In most motor-driven recorders the frequency of the motor power input may also be used to determine the Recording-Line Frequency as in 1.1.4.1 Scanning-Line Frequency.

BASIC TEST: Where high accuracy is required, the recommended method using standard one-second (or other) pulses can be applied much as described previously for the transmitter scanner. With the recorder under test separate from the one on which the pulses are being recorded, it is necessary to obtain from it in some way a sharp pulse marking each stroke. If no simpler arrangement is available, this can be accomplished by using a transmitter locked with the receiver under test. The transmitter scans a single line copy as if it were itself under test, and puts out the desired signal. The record of this signal pulse, superimposed on the standard signal pulse, is obtained and the stroke timing compared with the standard in the same way as for the transmitter scanner test.

As an alternative the test can be simplified by using the recorder to be tested for recording the signals. In this case it is not always necessary to use a separate signal pulse from the recorder. Instead the parallelism of the line from the standard pulse may be measured to the edge of the sheet.

The further alternative using the counter requires a signal pulse per stroke from the recorder under test, successively to open and close a gate as in the test for the transmitter scanner. The stroke duration is again measured by the number of standard frequency cycles passing through the gate.

1.1.5 *Spot Speed*

The spot speed, assuming linear scanning, is equal to the total scanning line length (see section 1.1.1) multiplied by the stroke speed (see section 1.1.4). Since the spot speed is usually measured in linear units per second, and the stroke speed in strokes per minute the figure obtained must in general be divided by 60.

1.1.6 *Reproduction Speed*

Reproduction speed is a measure of the rate at which a facsimile system will reproduce an area of subject copy.

If the useful line length, stroke speed and number of scanning lines per unit length are known, the reproduction speed may be obtained by multiplying useful line length by stroke speed and dividing by lines per unit length. This will provide a figure for the area recorded per unit time.

BASIC TEST: An alternative direct measurement (when these figures are not immediately available) is to determine by stop watch, or other means, the time to record a length of copy. Measure the area (on the subject copy) of the amount of material actually recorded. Dividing the measured area by the recording time provides the reproduction speed. This should obviously agree, to the order of accuracy of the figures, with the computation in the previous paragraph.

It is also possible to base reproduction speed on the area of recorded copy. This will vary from that based on subject copy where there is either enlargement or reduction in the process. Where figures are given they should state the basis to which they refer.

1.2 *Fine Structure of Copy*

1.2.1 *Spot Dimensions*

Neither a scanning nor a recorded spot is likely to be a sharply defined figure of uniform illumination or density. Consequently it is necessary to provide a definition that in some way averages the uneven or irregular nature of the spot to give a sharp specific dimension that can characterize its size.

There are two criteria that have been used to formulate the sharp dimension. One of these is related to the signal spectrum and effective resolving power of the spot, and this is described in section 1.2.1.1.1 and used in several other sections. It is specifically used where the resolving power of the spot is of particular importance in the test.

The second criterion is related to the reproduction of a flat field in the recorded copy, in areas where the subject copy shows a flat field. This is described in section 1.2.1.2.1, and also used in several other sections. It is used particularly where the tests involve dimensions which are critical in determining the presence of scanning line structure in the recorded copy. Thus there is generally no conflict between the uses of the two criteria.

The two criteria are not usually the same, but lead generally to figures which approach each other as the spot configurations become more perfect and well-defined.

1.2.1.1 *Scanning Spot*

1.2.1.1.1 *X Dimension*

There are two concepts involved in the dimensions. One of these is the purely geometrical concept. Where the spot has sharp boundaries, a given geometrical dimension can be measured directly, say with a microscope. The second concept involves the electric characteristics together with the geometric spot. For example, a given scanning spot may have a very small geometric **X** dimension (along the scanning line). But if the scanning process is dominated by a narrow pass-band filter, the *effective* spot size may be conceived of as broadened by the action of the filter.

The combined concept is that used in the 1956 Definitions of Terms, in linking the definitions of maximum keying frequency and scanning spot **X** dimension. (*Maximum Keying Frequency:* The frequency in cycles per second numerically equal to the Spot Speed divided by twice the Scanning Spot **X** Dimension. *Scanning Spot X Dimension:* The effective scanning spot dimension measured in the direction of the scanning line on the Subject Copy.) The definitions do not, however, give a precise meaning for "effective." It is necessary, in addition, when using the combined concept, to state where in the system, with respect to band-limiting filters, the electric signal is being taken.

As noted there is a close correlation between what can be characterized as the "effective" scanning spot size and the frequency band of the generated signal. Thus, the criterion used for "effectiveness" must be one that, as far as reasonably possible, establishes equality both of resolution capability in the spot and spectral distribution in the signal over a variety of configurations in the spot and in the signal band.[7]

A simple spectral distribution in the signal baseband consists of equal component magnitudes, with no phase distortion, from zero frequency up to a cutoff frequency F, as illustrated in Figure 5 at

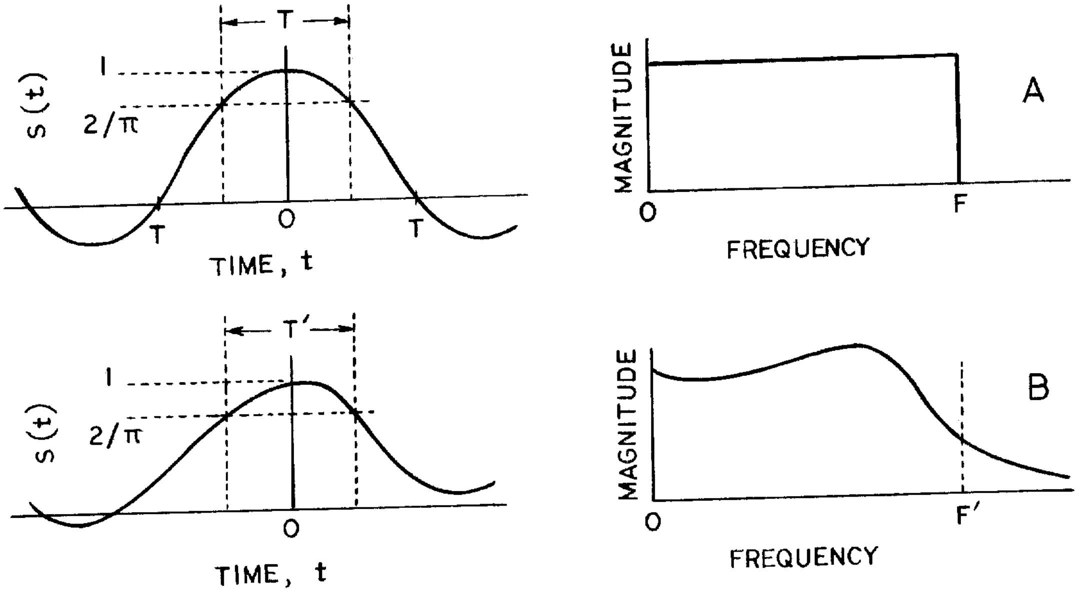

FIGURE 5

A, with zero magnitude beyond F. As indicated by Nyquist,[8] this transforms to a signal which goes to zero magnitude at $-T$ and T (and also at integral odd multiples of these), where $T = 1/(2F)$, and where

$$S = [1/(2\pi tF)] \sin (2\pi tF) \quad (10)$$

Here

$S =$ normalized signal voltage (or current)

$t =$ time, in same units as T (or $1/F$)

The time T is called the "Nyquist interval." Within a Nyquist interval element centered on zero time, the useful signal extends from $-T/2$ to $T/2$. At zero time itself, $S = 1$. At the edges of the Nyquist interval element, $t = \pm 1/(4F)$, and

$$S = (2/\pi) \sin (\pi/2) = 2/\pi \quad (11)$$

A criterion of the resolving capabilities of the spot must lie in the signal configuration near zero, say in the Nyquist interval element centered about zero. A simple quantitative measure of this configuration is the drop in magnitude from the center to the edges of the Nyquist interval, namely to $2/\pi$ of the peak.

Then if one has an arbitrary spot which leads to a signal as illustrated at B in Figure 5 (for some specific modulation arrangements, the negative portion of the signal may be folded up above the zero line), a criterion of its resolving capabilities can be taken as indicated by the time T' measured between the points at which the drop in voltage (or current) is to $2/\pi$ times the peak value. It is clear, of course, that if the spot is too irregular, or distorted, the idea of equivalence in resolving capabilities becomes meaningless.

If then T' is taken as the "effective" Nyquist interval, half the reciprocal, or $F' = 1/(2T')$ can be considered as the "effective" frequency band of the spectrum that transforms to the arbitrary spot configuration. This is illustrated at the left of Figure 5 B.

The above procedure is a sensitive method, therefore, of measuring the effective frequency band where the cutoff is not sharp. It is also a basis for defining the scanning spot X dimension.

BASIC TEST: The subject copy is taken as a fine line of known width across the direction of scanning. The electric signal is measured at the point which has been chosen in the system. If the signal is amplitude modulated, its instantaneous magnitude (or instantaneous carrier amplitude) is measured, say on an oscillograph. If it is frequency modulated, the instantaneous frequency can be converted into an instantaneous magnitude by a discriminator which is so chosen, for the measurement, as not to introduce signal distortion. For other types of modulation suitable arrangements may be devised.

On the oscillograph the points are

noted, on each side of the peak, at which the signal drops to $2/\pi$ of the peak value (measured to the steady background signal as a reference zero). The distance between the points, translated to the value on the subject copy itself, is taken as the provisional Scanning Spot X Dimension.

The exact broadening effect of the subject copy line width is complicated. However, when it is small it adds approximately in quadrature to the spot dimension.[9] Thus the corrected spot X dimension is

$$X = \sqrt{x^2 - w^2} \qquad (12)$$

where X = corrected spot dimension
x = provisional spot dimension
w = subject copy line width

If one desires to use the pure geometric concept for measuring the X dimension, and the spot edges happen to be diffuse, the same technique can be used, except that the electrical point chosen in the system must be one prior to any filtering (this provided that the photocell transducer itself is not limiting the band).

There are alternatives in procedure that may be used in special cases where convenient.

(*Alternative a*) Frequently, the pass band of the facsimile transmitter is sufficiently wide not to be the limiting factor in the transmission of the facsimile signals. Under such circumstances, and where the actual physical aperture is sharp, and is projected sharply on the subject copy, purely geometric measurements may be made. For example, the actual aperture used to form the scanning spot can be calculated using the lens formula:

$$X = vU/u \qquad (13)$$

where X = spot dimension
u = lens to aperture distance
v = lens to subject copy distance
U = aperture dimension
F = focal length of projection lens

and where,

$$\frac{1}{F} = \frac{1}{u} + \frac{1}{v},$$

or finally

$$X = U \left(\frac{v}{F} - 1\right) \qquad (14)$$

Here u and v, in a thick or compound lens, are measured to the appropriate principal planes.

(*Alternative b*) The geometric measurement may also be made by perpendicularly scanning very slowly a narrow line of known width, and by measuring both the displacement of the scanning spot with respect to the subject copy line and the carrier amplitude of the signal emitted by the transmitter. A gauge may be mounted on the device used to move the line and the distance moved measured in thousandths or even ten-thousandths of an inch (or hundredths or thousandths of a millimeter). The actual measurement consists of a series of static readings of displacement and amplitude. The scanning spot X dimension may be found from a plot of the readings as in Figure 6. If the aperture is round, the

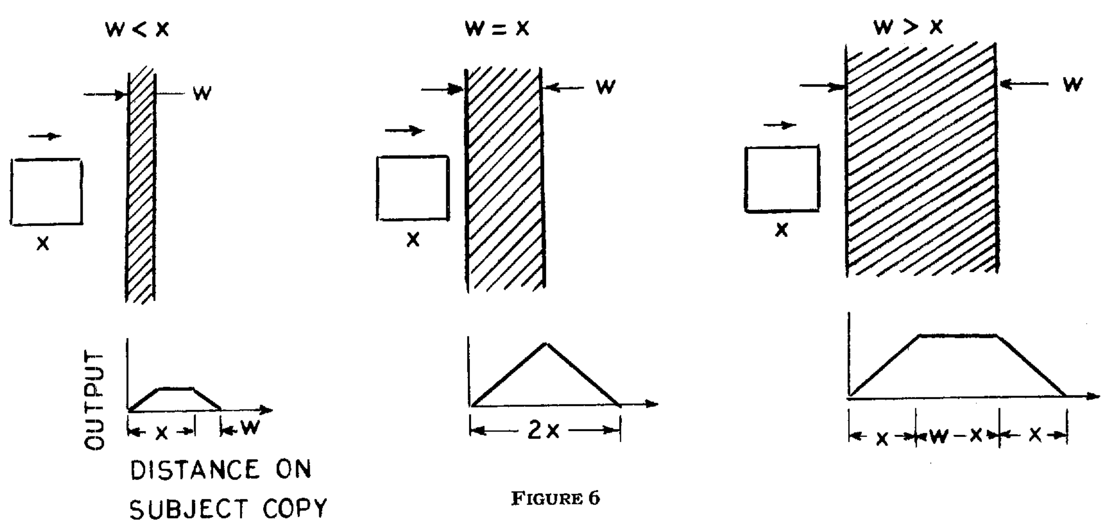

FIGURE 6

amplitude rise will not be linear but will approach maximum and minimum values of the amplitude tangentially, making it necessary to estimate where the curves reach maximum and zero. Figure 7 shows

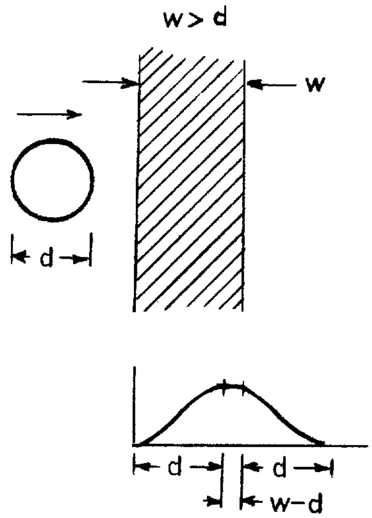

FIGURE 7

the value for the diameter d. The effective scanning spot **X** dimension will be somewhat less than d (for a sharp aperture it will be $d\sqrt{1-(2/\pi)^2} = 0.771d$. It can be measured directly from the $2/\pi$ points in Figure 7 by subtracting w in quadrature (as in equation (12)) from this separation.

(*Alternative* c) A special technique may be used for sharp rectangular apertures in which alternate black and white lines are scanned rapidly or slowly. If the width of these black lines and white lines are each equal to one half the scanning spot **X** dimension, the output will be a constant (Figure 8). Pattern 13 of the IEEE Test Chart may be used. The technique is actually usable for other spot shapes if they are not too irregular.

1.2.1.1.2 *Y Dimension*

In this dimension (perpendicular to the direction of scanning) the geometrical and combined concepts in general agree. This is because it would take a very special type of electric comb filter (and one not likely to be used) to influence the scanning process in this respect.

BASIC TEST: The general method of measuring the **Y** dimension consists in scanning a subject copy containing a fine line of known width w, at a very small

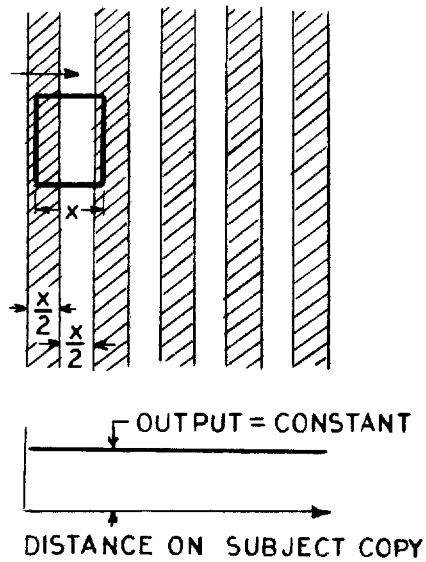

FIGURE 8

angle to the scanning lines, so that it crosses only a very few scanning lines in the entire length (not just available length) of the scanning lines. The exact number of the scanning lines spanned is measured from the jogs appearing in the recorded copy, (with an allowance to extrapolate from the available lines to the entire lines), and is called m. Then as the spot advances along the x direction of the copy, it samples the fine line at different parts of its own y coordinate (see **A** of Figure 9). Thus the output, viewed in an oscilloscope or oscillograph, will be as at **B** of Figure 9. The output may

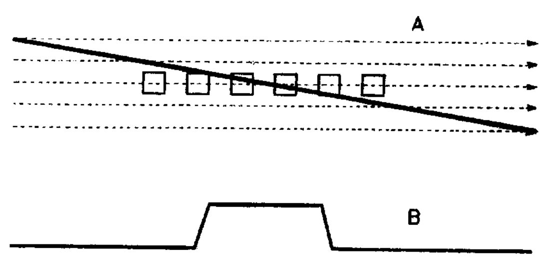

FIGURE 9

be repeated by disabling the scanner motion in the y direction. This output is entirely analogous to Figure 6, and correction may be made to the reading for the width of the subject copy line in exactly the same way, namely by subtracting w in quadrature (as in equation (12), from the separation of the $2/\pi$ points.

It is necessary, however, to convert the time dimension t on the oscilloscope into a y coordinate. The y coordinate is

$$y = tmFA \qquad (15)$$

where F = scanning line frequency (see 1.1.4.1)

A = nominal line width (see 1.2.2)

The various alternatives in 1.2.1.1.1 may also be adapted to measuring the *Y* dimension.

1.2.1.2 *Recorded Spot*

1.2.1.2.1 *X Dimension*

The recorded spots are apt to be irregular in density, shape, or size, or sometimes to be made up of a cluster of smaller spots. Nevertheless the *X* dimension has been defined in the 1956 Definitions of Terms as the largest center-to-center spacing between recorded spots which gives minimum peak-to-peak variation of density of the recorded line.

BASIC TEST: It can be measured by feeding the recorder with a signal of the type schematically indicated on line A of Figure 10. It consists of short pulses

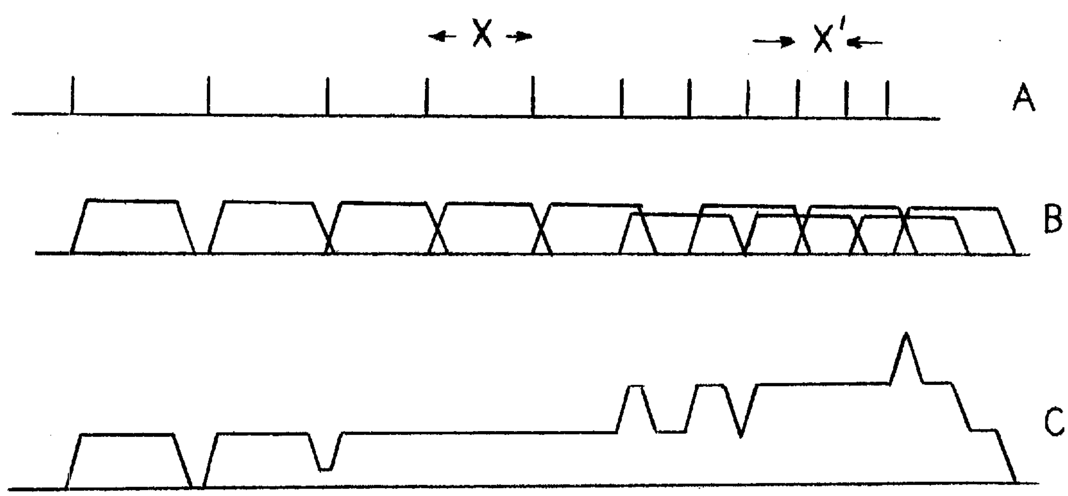

FIGURE 10

(short, that is, compared with the order of the expected **X** dimension) emitted at gradually decreasing intervals. Basically it can be obtained from a pulse generator arranged for a gradual variation of the pulse repetition frequency.

It is understood that in practice the signal would be modulated to fit the modulated signal used by the recorder. The simplest results are obtained by inserting the signal at baseband at the point in the recorder where the normal signal is also at baseband, but this may not always be possible, and some other arrangement needed.

The individual recorded spots are schematically indicated in line B. The individual spots cumulate to the final recording in line C. This shows variations of density along the scanning line which reach a minimum at the two pulse spacings *X* and *X′*. The spacing **X**, being the larger, gives the recorded spot *X* dimension, after translation from the signal time scale to the distance scale along the record copy.

It is clear that this procedure will not work with all modulation and demodulation systems, and indeed that the definition itself of the dimension is not meaningful for all such systems. This is indicated by Note 2 to the definition, which limits it to equipment giving a succession of discrete record spots in response to a constant density in the subject copy. The test which has been described has a somewhat larger range of validity than expressed in the note, but it can break down for example where the spot is too irregular. The variety of possibilities, however, is too great to warrant a detailed analysis.

Precautions must be observed when the measurements are influenced by special characteristics of the receiver. For example the size and possibly the configuration of the recorded spot may change with intensity of recording. Generally, the recording spot gets larger as the intensity increases, and measurement should be made for the density of interest on the record sheet. If there is a transfer process between the record medium and the record sheet, such as photographic printing from a received negative, the spot size may get smaller with increase in intensity. For some electrothermal recording, the spot appears to consist of small irregularly shaped gray marks. As recording level increases, more of the small marks may appear, changing the shape of the over-all recorded spot as well as its size and density. Again in each case, measurement is to be made at the density of interest. But, as already noted, where the spot is too irregular, the meaning of its X dimension may be lost.

1.2.1.2.2 *Y Dimension*

The definition for the *Y* dimension is basically the same as for the *X* dimension. Consequently the same measurement could be used conceptually. This involves recording at progressively closer scanning line spacings, and noting the greatest one at which the variation of density across the line is a minimum. Such a procedure is feasible with some types of recording mechanisms.

BASIC TEST: It is, however, impractical with many types of mechanism. For these an indirect method must be used.

The first step consists in analyzing from the nature of the process what quantity is additive in the recording. In many cases this will hold well enough for the density of the recorded spot, but sometimes other quantities will be needed to fit this condition.

The next step consists in recording a white field with a single black scanning line marking, as at A of Figure 11. Here

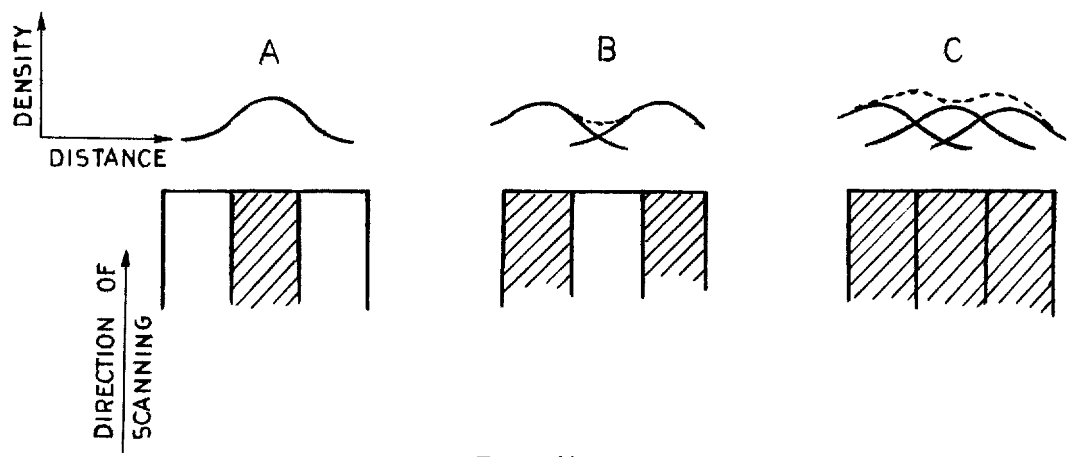

FIGURE 11

the chosen additive variable is plotted as the ordinate, and it is measured with a microdensitometer or the equivalent.

Then at B two marking scanning lines, separated by a spacing line, are recorded. The chosen additive variable is measured and plotted. It can also be computed by using the curves from A, suitably separated and added together. The departure between the directly measured and computed results is a measure of the reliability of the process.

Further, a complete field of marking lines can be measured, as at C. Here again the measured variable can be compared with computations from the individual curves, to give a further measure of the reliability.

Finally the individual curves may be added with a variety of separations, both greater and less than that of the actual machine. The completed curve may, if not already so, be translated into a density curve. The largest separation which gives a minimum peak-to-peak variation defines the recorded spot Y dimension.

If a transfer process is involved in going from record medium to record sheet, the minimum peak-to-peak density variation should be figured for the recorded spots on the final record sheet.

For certain special cases some simple alternatives may be used.

(*Alternative a*) If the recorded spot has a direct relation between X and Y dimensions such as in the case of round or square spots the Y dimension may be found by first measuring the X dimension.

(*Alternative b*) A good approximation may often be made by knowing or computing the distance progressed from recorded line to line (Nominal line width, 1.2.2) and estimating visually the amount of overlap or underlap (see 2.2.1 to 2.2.4) using a calibrated microscope to view the recorded lines.

1.2.2 *Nominal Line Width*

BASIC TEST: To measure the nominal line width on the recorded copy one can place a scale of inches or centimeters perpendicular to the recorded lines and count the number of lines per unit length.

Complications may arise where the record copy passes through a damp or wet stage and shrinks in drying, and where one is interested in the nominal line width at the time of recording rather than in the final state of the copy. The simplest procedure would be to obtain the figure from direct measurements on appropriate parts of the machine. If this is not feasible one can measure the shrinkage in the copy by exposing it to fiducial marks having a fixed separation, under the same conditions as the recording process, and then measuring the separation between the marks in the final copy.

BASIC TEST: To measure the nominal line width in the subject copy one counts the lines between two distinct picture features in the recorded copy. Then one measures the separation between these features in the subject copy used. The separation divided by the number of lines gives the nominal line width.

1.2.3 *Facsimile Picture Element*

The 1956 Definitions of Terms did not define the term "facsimile picture element." However by the use or adaptation of the testing procedures described above it is possible in general to give a meaning to this concept.

The concept stems from a recognition of limitations of the scanning and recording process and line transmission. Because of all these it is not possible to reproduce every single point in the subject copy by a corresponding point in the reproduction. Instead, finite areas appear in the record copy which typify corresponding areas in the subject copy, but do not match them in interior detail. Such an area has been more or less loosely called a "picture element." It is of course in general larger than the recorded spot, because it includes broadening effects of limitations in the scanning process and line transmission—as well as a certain difference in definition.

BASIC TEST: The *Y* dimension of the facsimile picture element is to be taken as the nominal line width covered in 1.2.2 immediately above. This has meaning for the facsimile picture element only if the *Y* dimensions of the scanning (1.2.1.1.2) and recorded (1.2.1.2.2) spots are each not larger, or at least not much larger, than the nominal line width.

The *X* dimension of the facsimile picture element may be considered as an over-all spot *X* dimension for the complete facsimile system consisting of transmitter, transmission medium, and receiver. It can be measured by scanning a fine white line of known width on a black field (or a fine black line on a white field) in the subject copy. There is measured on the final record copy, with a microdensitometer, the densities of the reproduced line along the direction of scanning (*x*-direction). It may be found that these vary according to the *y* coordinate at which the measuring is done. If so, measurements can be made at enough of a variety of *y* coordinates for the average to be significant.

The density readings are converted into reflected light (or luminance) ratios *L* by taking the antilogarithms of the densities *d*, i.e.:

$$L = \text{antilog}_{10}\, d \qquad (16)$$

When plotted, this gives a curve like those of Figure 12 at A (white line on black) or B (black line on white).

The $2/\pi$ points are taken as in the case of the signal in section 1.2.1.1.1, and as illustrated in Figure 12. From the distance between the

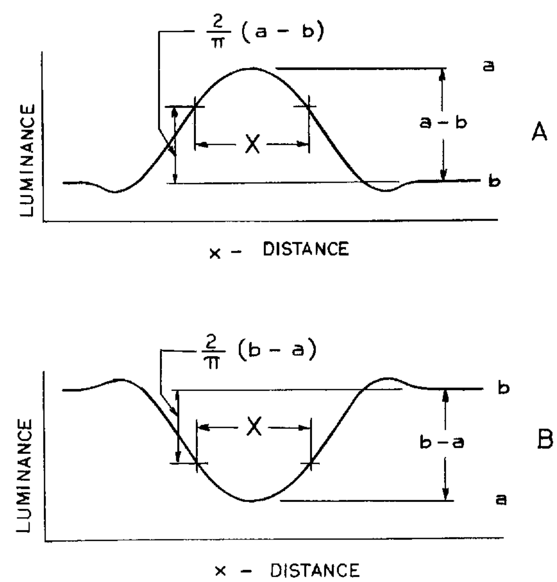

FIGURE 12

points, on the final record copy, there is subtracted in quadrature (as in equation (12)) the corresponding width of the subject copy line (by "corresponding" is meant increased or diminished in proportion to the magnification or reduction of the record copy as compared to the subject copy). The corrected separation is then taken as the X dimension of the facsimile picture element, in the record copy.

This X dimension may of course not be meaningful if the scanning or recorded spots are too irregular, or if the equalization of the transmission medium, in phase or attenuation, is too irregular, or if there are other serious defects in the system.

1.3 *Facsimile Definition*

1.3.1 *Over-all Definition*

The Definitions of Terms lists "definition" as "distinctness or clarity of detail or outline in a record sheet or other reproduction." The clarity required of a given facsimile system will depend upon the requirements of the system user. For instance, a facsimile system designed to send business letters might be required to give only legibility of the received copy by one user, while another user might require that it not be possible to detect that facsimile has been used. The type or types of checking or testing methods which are most useful will also depend upon the application, and no single test can be considered universal.

Examples of testing methods are:

- Test pattern reproduction
- Readability of type faces
- Other specific methods for individual applications

The following note of caution is to be included as part of the group of methods of testing definition:

CAUTION: Results obtained with one method of measuring definition will not necessarily correlate with results obtained from another method. For example, cases may occur in which the readability for one sample might be higher than for another, but the test pattern reproduction would be reversed. Characters scanned in different directions may give different readability results. Also the probability of the heterodyning of the modulating and carrier frequencies may introduce variations between definition as determined with various test chart patterns.

1.3.1.1 *Measurement of Definition by Test Pattern Reproduction*

Definition can be tested by using the NBS Tri-Bar Chart as printed in pattern No. 9 in the IEEE Facsimile Test Chart. Definition is expressed in terms of the smallest Tri-Bar group where three lines can be distinguished visually in the received copy and where three lines can be distinguished in all larger groups. Numerically, the definition is expressed as the number of lines per inch corresponding to the Tri-Bar group resolved. This is listed in the instruction sheet in terms of the subject copy so that if the record copy is expanded or compressed, this ratio should be considered when expressing the definition resolved in the record copy.

Pattern No. 9 is generally the most useful for this test, but occasionally patterns Nos. 11, 12, 13, and 17 may be used for special purposes.

1.3.1.2 *Type-Face Readability*

This technique is used to obtain a general index of definition and quality of a system. Transmit pattern No. 14 of the IEEE Test Chart and determine the smallest printing on the received copy which can be read satisfactorily. Results may differ for various observers due to differences in standards of appraisal.

1.3.1.3 *Alternative Readability Technique*

BASIC TEST: This technique is more exact than the above, and ends with a more reliable specific figure. The subject copy used is special and consists of blocks of printed letters. Each block contains 100 letters usually arranged with ten per line and with each letter unrelated to adjacent ones, to avoid recognized relationships. Generally, for each size of type there are three blocks; one with the rows of letters parallel to the scanning lines, one at 45°, and one perpendicular. Additional groups of three blocks are used, each group for a different size of type. This subject copy is transmitted, and a count is made of the readable individual letters in each block of type. This results in a set of evaluation figures. For example, a result might be:

4 point type— 50% readable

6 point type— 90% readable

8 point type—100% readable

Where important, several independent readers may be employed. The type face used should be representative of those for which the facsimile system will be employed since results will vary with different styles of type.

1.3.1.4 *Other Testing Methods*

For special purposes other testing methods have been used. For example[10] the "acutance" has been measured. This is an integrated function of density across a sharp demarcation from black to white. The test was first introduced in photography.

1.3.2 *Facsimile Transmitter Definition*

See cautions listed under 1.3.1.

1.3.2.1 *Complete Transmitter*

The transmitter definition in the sense of the finest subject copy pattern that can yield a fully modulated signal, may be measured through the use of patterns Nos. 11 and 17 of the IEEE Test Chart. The scanning mechanism is operated by hand and an indicator such as a decibel meter is used to check the output of the transmitter. If the output of the facsimile transmitter is a frequency shift signal a frequency meter can be used as an indicator. First the contrast of the transmitter is adjusted using the black and white portions of the pattern, noting the deflection of the indicator as full black or white is reached. Manually the scanning spot is slowly moved back and forth across the pattern, starting at a wide portion of the pattern (near 0.06) and progressing with each traverse of the pattern toward the narrow (0) end of the pattern. For initial scans full "black" or "white" output indication should result when the scanning spot is on the pattern. A measure of effective definition is found from the narrowest part of the pattern which results in full black or white response. Pattern No. 11 indicates the limit to full white, and Pattern No. 17 to full black, response.

Differences in results may be caused by halo effects. For instance in systems where the scanning spot is formed with the incident light used for scanning there often is a large area of low intensity light forming a halo around the spot. This may not have appreciable effect on the capability of the scanner to resolve small patterns or printing but it may result in not being able to attain full black response for pattern No. 17 even though the part of the pattern being scanned is wider than the principal part of the scanning spot of light. In this case an output indication close to full black is established and used instead of full black indication. The exact details of this operation will vary with individual cases, and when results are announced, enough should be stated to make them understandable.

For adequate readability of small printing and for transmission of lines in an original copy which are narrower than the scanning spot full black response of the system is not always necessary provided the recording system at the receiver is capable of reproducing shades of gray. In such cases the measure of effective definition should be qualified by stating the percentage of full black response used as a criterion. (See 1.2.1.1 Scanning Spot.)

1.3.2.1.1 *Alternative Procedures*

BASIC TEST: For facsimile transmitters with amplitude varying output signals pattern No. 9 may be used with a synchronized oscilloscope to determine the smallest group of three lines which may be clearly discerned in the signal. This may also be observed using transmitters with frequency modulation or frequency shift output but due to difficulty in visually separating two frequencies when very few cycles of each frequency are present it is more advisable to have access to the signal as amplitude modulated. This can be accomplished through the use of a discriminator with known good transient characteristics.

Transient response of the facsimile transmitter, and the definition which one can expect of the final copy, are closely related. This transient response may be evaluated using an oscilloscope and patterns Nos. 3, 4, 5, 9, and 19. Observations are made of signal rise and fall characteristics and echo effects. The oscilloscope patterns resulting from the wider black patterns are examined to determine whether a) rate of rise is compatible with the time it takes the scanning aperture to pass completely past the leading edge of the black pattern, b) there are oscillations as the full black level is reached (these may cause light gray echoes in the received copy), c) the signal decay due to the trailing edge is sufficiently rapid and d) there are oscillations after the trailing edge which may cause black echoes in a received copy. (See also 3.3.1 Tailing, and 3.3.2 Echo.)

1.3.2.2 *Scanner Only*

The principal difference between the measurement of the complete transmitter and of the scanner only lies in the portion of the electric equipment where the signal indicator is inserted. This location particularly influences the nature of the modulation of the signal, which for instance may be amplitude modulated at the immediate output of the scanner, but frequency modulated at the output of the complete transmitter. The indicator used must therefore be chosen appropriately. Another possible difference lies in the circuit impedance at the monitoring position, and the signal susceptibility to bridged resistance or capacitance. This influences the input circuit requirements on the indicator chosen.

1.3.3 *Facsimile Receiver Definition*

1.3.3.1 *Complete Receiver*

BASIC TEST: Square wave signals with appropriate modulation, impedance and voltage characteristics from a generator circuit are applied to the input terminals of the facsimile receiver. Recordings are made for a number of different square wave frequencies corresponding to recorded marks which range from wider than the expected definition to much smaller. The recorded copy is examined to determine the smallest recorded dots with clear spaces between and to look for unwanted transient patterns. Tests should be repeated with different gain control settings, adjusting the square wave generator signal level so that the recordings range from dark grey (near black density) to light grey (near white density) so that transient overshoots will not get into the "blacker than black" or "whiter than white" ranges. To avoid possible overload of early stages of the receiving amplifier the peak input level should not be permitted to exceed specified maximum level. Extreme care must be taken in the selection of a correctly operating square wave generator and modulator system to insure that a satisfactory signal is obtained. Often the commonly used techniques for testing such signals are not as sensitive to the distortions being considered as is the facsimile receiver. One way to check the square wave generator is to use it to provide signals to a facsimile receiver which has been proven to be satisfactory through previous use in a facsimile system. The square wave pattern recorded should not have echoes and should show sharp transition from black to white and vice versa. In order to simplify viewing of the recorded copy, and to check the limiting clear spots, it is desirable to synchronize the square wave repetition rate with the recorder so that there are an integral number of pulses per time required to sweep a recording line length (analogous to scanning line length, but at recorder). This will merge the spots into lines perpendicular to the scanning lines.

1.3.3.1.1 *Alternative Procedures*

There may be receivers in which pattern effects accentuate succeeding bars in a square wave signal and give spuriously high apparent resolution. To avoid this effect one can use a pulse generator instead of the square wave generator. The pulses are of short duration compared to the time between pulses and are usually synchronized to obtain an integral number of pulses during the time of sweeping a recording line length. Appropriate modulation is employed and the pulse width is varied to determine the smallest dot which can be recorded. (See caution in 1.3.1, Over-all Definition.)

For frequency shift signals, in addition to the above, several frequency shift ranges should be used, such as white to black, grey (near white) to grey (near black), grey (near white) to grey (near mid-range), etc. This helps isolate resonance or other conditions which affect only certain frequency ranges.

If a facsimile transmitter which has been operated in a facsimile system and, therefore, is known to have satisfactory characteristics is available and will cooperate with the facsimile recorder under test, it provides a very versatile test unit since almost all patterns of the test chart can provide some information regarding definition.

1.3.3.2 *Recorder Only*

The same comments apply generally here as to 1.3.2.2 Scanner Only. However, it is the square wave or pulse generator, rather than signal indicator, which is to be bridged at the immediate recorder input (or input of the recording amplifier, or at some appropriate point ahead of this). It is this generator output impedance which must be so chosen as not to disturb the existing circuit. And, again, the generator output signal form must be appropriate to the testing location chosen (i.e., amplitude modulation, frequency modulation, etc.).

1.4 *Halftone Characteristics*

The Definitions of Terms lists this as "A relation between the density of the recorded copy and the density of the subject copy." A note adds that "The term may also be used to relate the amplitude of the facsimile signal to the density of the subject or the record copy when only a portion of the system is under consideration. In a frequency-modulation system an appropriate parameter is to be used instead of the amplitude."

The basic problems involved are therefore first measurements of density, and second, where needed, measurements of appropriate characteristics of the signal at various places in the complete system.

1.4.1 *Density (in Facsimile)*

This is listed in the Definitions of Terms as:

"A measure of the light-transmitting or reflecting properties of an area. It is expressed by the common logarithm of the ratio of incident to transmitted or reflected light flux."

"Note: There are many types of density which will usually have different numerical values for a given material; e.g., diffuse density, double diffuse density, specular density. The relevant type of density depends upon the geometry of the optical system in which the material is used."

BASIC TEST: In facsimile both the subject copy and record copy are most often opaque, so that the density principally needing measurement is the diffuse reflection density. The facsimile problems here are very similar to those of photography. Thus the American Standard covering diffuse reflection density for photographic applications (PH 2.17-1958, approved June 18, 1958) can usually be used as a specific guide for testing methods.

The general procedure described in this Standard consists in irradiating a sample and making two measurements of the reflected radiation. The first is with the sample desired to be measured in place, and the second with a calibrated sample substituted for it. The standard calibrating sample is a suitably prepared magnesium oxide surface, but it is also possible to use any suitable white ceramic tile or even photographic paper if these are calibrated some time against the Standard. For details see the American Standard referred to, and also Letter Circular LC-547, National Bureau of Standards.

The density is taken as the common logarithm of the ratio of the response for the standard surface to the response for the sample measured.

The principal precautions needed, and cited in the American Standard, when making the measurements, are:

a) Specular reflection of the radiation, coming from gloss of the sample surface, is to be avoided. This is achieved by requiring that the incident radiation be restricted to elevation angles between 40 and 50 degrees to the normal, and that the collection system accept reflected radiation lying between 0 and 5 degrees to the normal.

b) Particular influences of the surface texture of the sample are to be avoided. This is accomplished by requiring incident radiation uniformly distributed at all azimuths, and a collection system accepting all azimuths.

c) Where the visual diffuse reflection density is desired, the spectral distribution of the incident radiation is to be controlled to some specified standard (such as 3000 degrees Kelvin black body radiation), and the photosensitive receptor is to be either the human eye, or a receptor meeting the spectral sensitivity specified for the Standard Observer.

d) Where photographic or other paper is being evaluated, it is to be backed by an opaque white material with a reflectance of not less than 85 percent.

e) For most practical work the numerical results obtained are not too sensitive to the exact angular beam specifications cited, to the need for irradiation at all azimuths (particularly if the sample itself is shifted in azimuth for several readings), or to the choice of oblique incidence for radiation and normal collection (as against normal incidence and oblique collection).

Commercially available reflection densitometers take the liberties suggested in item e) above. One model uses oblique incidence and normal collection. It works at only one azimuth (plus or minus the 5 degrees of a circular cone of incident and, also, collected light). In normal use, the light source is merely a 6-volt lamp whose current may be adjusted to produce a luminous intensity of 15 candelas. The receptor unit is a photocell with d-c amplifier, which has more sensitivity in the near ultraviolet than the human eye. Provision is made for filters so that where it is important, the combination light source and receptor sensitivity spectrum can be adjusted to one of those suggested in the American Standard.

1.4.2 *Over-all Characteristic*

Patterns Nos. 7 and 8 of the IEEE Test Chart are transmitted through the facsimile system to be measured. The resulting facsimile copy of the tablets is compared step by step with the subject tablets. Where needed several recordings should be made and the density measurements averaged. The results are plotted as shown in Figure 13. The curve through the points plotted for the recorded density of each step as a function of the original transmitted density gives the required half-tone characteristic of the facsimile system under the conditions measured.

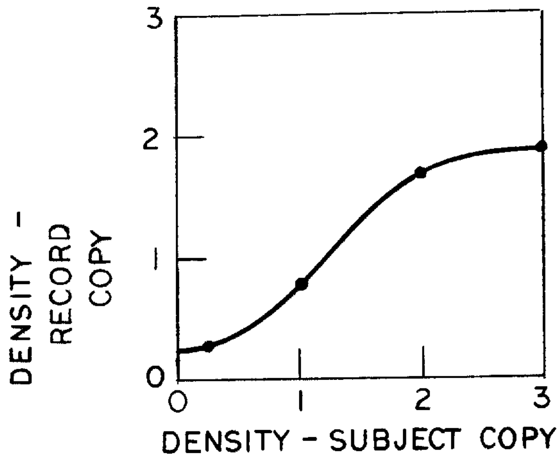

FIGURE 13

1.4.3 *Facsimile Transmitter*

1.4.3.1 *Complete Transmitter*

The half-tone characteristic of the complete transmitter is measured by transmitting the tablets of the IEEE Test Chart and measuring the electric output of the transmitter for each successive step of the tablets (see 1.5.1 Facsimile Signal Level). The results conventionally are plotted as in Figure 14, showing the density as ab-

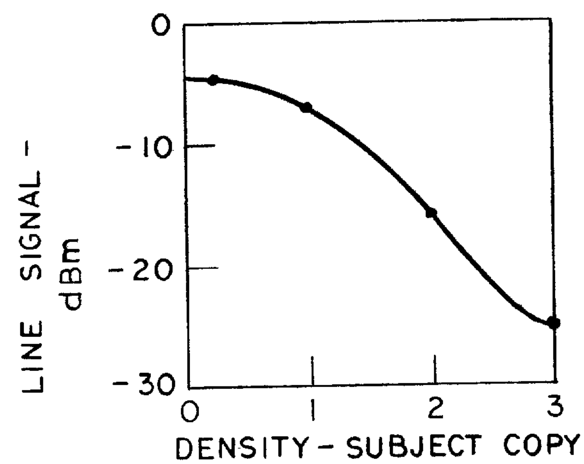

FIGURE 14

scissa and the signal level (usually measured logarithmically, say as dBm—decibels referred to 1 milliwatt—in the illustration) or frequency as the ordinate.

The signal will always be in the modulated form (unless baseband transmission—very rare—is used). Thus what is measured is the instantaneous envelope of the modulation where amplitude modulation is used, or instantaneous frequency where frequency modulation is used. For other forms of modulation the measurement will have to be specially devised.

BASIC TEST: It is in general more convenient to stop the scanner on the individual tablet steps of the subject copy for making the measurement. A conventional voltmeter, ammeter or frequency meter may be used. Otherwise the dynamic characteristic is measured (see below 1.4.5 Dynamic *vs.* Static Characteristic), and the signal amplitude will need to be measured with a dynamic instrument such as an oscilloscope or panoramic receiver.

1.4.3.2 *Scanner Only*

This will differ chiefly from the preceding in that the signal may be baseband. Then the signal is in the form of an instantaneous direct current. In some forms of scanner, such as those using light interruption modulation, the baseband signal never appears. Thus at the scanner ouput it can be in the same form, except possibly for circuit impedance, as at the output of the complete transmitter.

1.4.4 *Facsimile Receiver*

1.4.4.1 *Complete Receiver*

BASIC TEST: The half-tone characteristic of the complete receiver is measured by applying to the electric input of the system a series of increasing voltages, or waves of increasing frequency, as may be appropriate. Each value of the applied signal is maintained for sufficient time to record one step of a recorded density strip, and changes of input value are made at substantially equal time intervals so that the recorder produces a usable density strip. The measured results are plotted as in Figure 15 showing the density as ordinate and the voltage, current, power or frequency as the abscissa. To

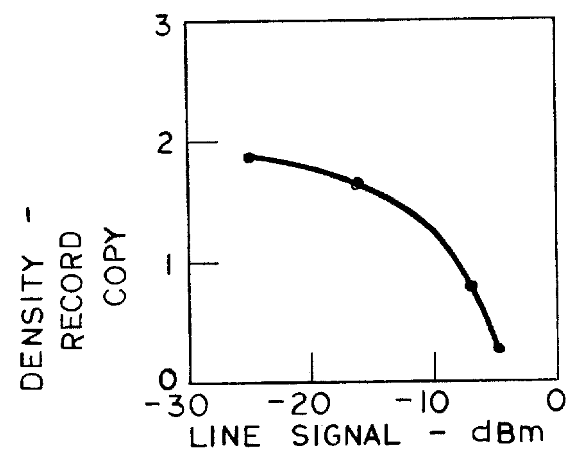

FIGURE 15

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check the dynamic characteristic (see 1.4.5) calibrate the output of a transmitter which is scanning patterns Nos. 7 or 8 of the IEEE Test Chart.

The signal measurement is made on the modulated signal. For amplitude modulation it is an instantaneous value of modulating envelope. For frequency modulation it is an instantaneous frequency. As in the case of the transmitter, other forms of modulation will require special measurement.

1.4.4.2 *Recorder Only*

As in the case of the transmitter this differs from the above chiefly in that the signal may be in the baseband form, and then may appear as an instantaneous direct voltage or current, which must be supplied for the measurement.

1.4.5 *Dynamic vs. Static Characteristic*

In carrying out the above measurements it is important to realize that the dynamic half-tone characteristic may differ appreciably from the static characteristic based on long-continued readings on each density step. To test this, the scanner is loaded with the two identical reverse density step tablets, patterns Nos. 7 and 8 of the IEEE Test Chart. Suppose that the required recording current is large compared with the power capacity of the rectifier and smoothing capacitor which supply it. At the end of the first strip, full black will not be reached because the supply voltage has been drawn down by the preceding demands for dark grey; at the start of the second strip, the black following the white margin will reach full density. There are of course many other factors which can modify the half-tone scale from the static condition. The difference in values of the corresponding steps of the double step tablet is a measure of the dynamic effect on the half-tone characteristic. This effect can be expected to change depending upon the rapidity of the change in copy from white to black or vice versa. Measurements of the dynamic characteristic should therefore be accompanied by an exact statement of the conditions involved.

1.5 *Facsimile Signal*

1.5.1 *Facsimile Signal Level*

This is defined as the maximum facsimile signal power or voltage (root-mean-square or direct-current) measured at any given point in the system.

The measurement should be made under actual operating conditions, viz., with the scanner being driven at normal speed and with normal lighting and pickup conditions. A voltage-calibrated cathode-ray oscilloscope can be used as the preferred type of indicator, but when no auxiliary signals are present, voltmeters or milliammeters may be used as operational indicators, if previously calibrated against the oscilloscope on a similar type of signal. The meter used must have a frequency response, ballistic characteristic, and an impedance appropriate to its use in the specific circuit concerned. The use of a "volume indicator" has proven satisfactory for measuring facsimile signal level where the signal lies in the voice-frequency band.

In observing the facsimile signal level at any point in the system, it is essential that all auxiliary signals, as used for synchronizing, phasing, framing, and the like, be ignored or eliminated from the observation. Those types of auxiliary signals that are unique as to their frequency are best eliminated by filtering; those that are unique as to time of occurrence are best eliminated by synchronizing the oscilloscope to the scanning line and then observing and measuring deflections only during the available scanning line.

The voltage corresponding to maximum deflection referred to the axis of zero signal is the usual desired measurement in the case in which the signal appears as varying direct current. Where the signal appears as a modulated carrier, the observed maximum voltage should be reduced by the sinusoidal form factor appropriate to obtain the root-mean-square value (i.e., divided by $\sqrt{2}$).

BASIC TEST: Facsimile signal levels representing "white signal" and "black signal" can be determined by scanning maximum white and maximum black copy respectively while reading the signal level on an oscilloscope or VU meter. In a frequency-modulated signal the level is independent of copy density.

The facsimile signal level can be expressed in decibels with respect to some standard value, such as 1 milliwatt or 1 volt at a specified impedance. In practice, high-speed systems often employ peak-to-peak measurements referred to 1 volt (or some similar value) peak-to-peak (without conversion to root-mean-square).

1.5.2 *Maximum Keying Frequency*

This is defined as the frequency, in cycles per second, numerically equal to the spot speed divided by twice the scanning spot X-dimension.

Test procedures for determining these two quantities are described respectively in 1.1.5 and 1.1.2.1.1. In the case of the latter it is essential to measure the effective spot size, i.e.,

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to include broadening effects caused by electric filtering.

No additional testing is therefore required to measure the maximum keying frequency. It is merely computed as one-half the ratio of the spot speed to the scanning spot X-dimension.

1.5.3 *Maximum Modulating Frequency*

This is defined as "the highest picture frequency required for the facsimile transmission system." The picture frequencies refer to the baseband frequencies resulting from the scanning of subject copy.

The effect of the scanning spot on the scanning process is to act as a filter[11] to attenuate the higher frequency components of the baseband signal, sometimes in tandem with electric elements which also affect filtering. Even a sharp well-formed spot gives a very significant amount of filtering.

Because of this filtering action the spectral components of the baseband signal diminish in magnitude with rising frequency. In practice the "highest frequency required" is usually taken as that above which the magnitude of the components is low enough for them not to be significant in reconstituting the picture at the receiver (assuming of course that filtering beyond the point of measurement is not limiting). It is to be recognized that this "highest frequency" is not very sharply defined.

BASIC TEST: In systems where the electric baseband signal is accessible, its alternating-current amplitude can be measured with an oscilloscope or similar high-impedance device whose presence does not change the signal. One uses for subject copy a repeated black and white line pattern such as pattern No. 13 of the IEEE Facsimile Test Chart or its equivalent. For the coarser parts of the line pattern (or lower baseband frequencies) the alternating-current amplitude on the oscilloscope is relatively independent of the line spacing of the pattern. As the line spacing becomes finer, however, the alternating-current amplitude diminishes.

At some point the alternating-current amplitude becomes small enough to be considered "negligible." This amplitude varies according to the conditions, namely the quality of the facsimile transmission that is expected; whether the principal transmission problems being considered relate to say picture sharpness or to interference, either to or from the facsimile circuit; or to other conditions. Illustrative figures might be an amplitude drop of 20 dB to 40 dB from the signal for the coarse line spacing.

The maximum modulating frequency f is computed from the number of black lines per inch (or centimeter) n in the subject copy, and the scanning spot speed s in inches (or centimeters) per second, as follows:

$$f = ns \tag{17}$$

There are facsimile systems in which the electric baseband signal either does not exist, or is inaccessible. In these systems one measures, instead, the upper and lower edges of the facsimile band, from which the facsimile bandwidth is computed. The difference is that this band exists *after*, and not *before*, modulation, so that the frequency is displaced, the nature of the signal may be changed, and the signal may have gone through additional filtering. (See 1.5.4 and 1.5.6.)

Also, there are *two* frequencies involved (at the upper and lower edges of the frequency band respectively) instead of *one*.

The measuring technique is very similar to that which is described in 1.5.4. The chief difference lies in the need for distinguishing the two edges of the band in the spectrum analyzer signal.

In simple cases such as for amplitude modulation it is possible to relate back to the maximum modulating frequency merely by using equation (17). In such cases the additional filtering undergone in the modulating process is of course included in the final result.

1.5.4 *Bandwidth, Facsimile*

The frequency spectrum of a facsimile transmission medium (in common with that of other communications systems) consists of three general portions. The first is the "pass" region which carries the main portion of the signal. This portion of the transmission path needs to be equalized to precise pre-set tolerances to permit reasonable fidelity in the transmission of the signal. Second is the "elimination" region in which there is a negligible signal power. This region can, for example, be allocated to other facilities if the "negligible" power is engineered to be low enough not to cause interference. In a carrier signal the elimination bands usually exist both at higher and lower frequencies than the pass band. The third general portion is the transition or "roll-off" region between a pass band and an elimination band. There is usually signal power of reduced amount in the roll-off region, and transmission distortion tolerances are progressively generous as one goes from the edge of the pass to that of the elimination band.

The demarcations of these regions can vary considerably according to the specific facsimile system one has in mind. However an illustration might be that a 3 dB drop in facility transmission from that in the pass band marks the edge of the roll-off band, and a 30 dB drop from that of the pass band marks the edge between the roll-off and the elimination bands.

High quality facsimile systems usually insert filters between the send and receive terminal equipments respectively, and the line facility. Thus the width of the frequency spectrum utilized does not vary from one facility to another. In such a case the problem of determining the edges of the various regions for a given terminal equipment consists largely in making appropriate transmission measurements within the equipment. For reasons of economy, explicit filters are sometimes omitted. In such cases the determination of the edges of the various regions in a given equipment can be uncertain, and it is possible to find it used flexibly with different bands on various facilities.

In specifying the characteristics of a facsimile terminal, "bandwidth" or other terminology may be employed to indicate what sort of circuit facility is required for adequate transmission of the subject copy which the terminal was designed to handle. The figures given are generally nominal ones and frequencies well outside the stated limits may be present in the transmitter output. These frequencies are generally not necessary for adequate transmission of the subject copy and may, in fact, result in degradation of the transmission due to delay variations, or nonlinearities, or other imperfections in the transmission channel.

BASIC TEST: The actual output of a transmitter may be measured with a spectrum analyzer while scanning representative subject copy or sections of the IEEE Test Chart. Patterns Nos. 3, 4, 5, or 9 would be suitable. To determine how much of the total transmitter output is required for adequate transmission an adjustable band-pass filter may be employed between the transmitter output and a directly connected recorder while reproducing representative subject copy, or the test chart patterns, and observing the spectrum on a spectrum analyzer. It will generally be found that signal amplitudes which are less than some small fraction of the maximum (say illustratively 10 percent, or 20 dB down) can be disregarded.

A number of factors enter into the practically useful bandwidth of a facsimile transmission channel. These include envelope delay (see 3.2.1), the attenuation-frequency characteristic (see 3.1), nonlinear effects (see 3.6), and the presence of compandors (see 3.2.1). All of these effects tend to reduce the proportion of the bandwidth of the facility, as set by limits of energy transmission, which can actually be employed satisfactorily.

1.5.5 *Effective Band*

This term is defined as a band equal in width to that between zero frequency and the maximum keying frequency. This last, in rather roundabout fashion, is really a measure of the resolving power of the transmitting machine along the X, or scanning line direction. Primarily, the width of a frequency band in the system is set by this resolving power (in the X direction) which is desired for the installation. But other contributing factors are the method of modulation, a desire for reduction of transient fringes in the copy, and certain economic compromises (such for example as that of using a wider band facility which does not need further equalization as against equalizing a narrower facility). The "effective band" then serves as a measure of how much of the band actually used contributes to the resolving power as set by the transmitter.

BASIC TEST: The test procedure for measuring the effective band depends upon the problem being faced. At one extreme the problem can be that one has a given machine and needs to fit a transmission medium to it. The determination of the effective band is then that of finding the maximum keying frequency of the machine (see 1.5.2). Although this is not mentioned in the Definitions of Terms, the potential resolving power in the record copy which this allows cannot be secured unless the receiving machine has a recording spot X-dimension which is effectively equal. By "effectively equal" one means that the X-dimension of one spot divided by its spot speed is equal to the X-dimension of the other divided by its spot speed. After having determined the effective band one can make engineering decisions on the method of modulation and the extent of roll-off desired, to determine the total frequency band needed in the transmitting medium.

BASIC TEST: At the other extreme the problem can be that one has a given transmitting medium and needs to fit a set of machines to it. One must then start with the engineering decisions on method of modulation and roll-off, to obtain the ratio of effective band which can be obtained to that of the total band. Thus after measuring the total band available in the medium one can estimate the effective band which this will permit. The effective band will then tell the maximum keying frequency. From this one can compute the scanning and recording spot X-dimensions which are needed.

1.5.6 *Vestigial Sideband*

As a means of achieving better channel utilization than is possible with conventional double-sideband transmission many facsimile systems employ vestigial-sideband transmission in which one full sideband and a "vestige" of the other (usually some 15-20 percent) are transmitted. The lower sideband is the one usually transmitted while the upper sideband is largely suppressed. The vestigial-sideband filter may be of the passive or active type but it must be designed carefully to avoid introducing additional delay distortion.

The vestigial-sideband filter may be a single unit associated with the transmitter or it may be in two separate units, one associated with the transmitter and one with the recorder. In any case the over-all amplitude-frequency characteristic is such that the carrier is ideally down 6 dB from the maximum with a rather precise relationship between the shape of the characteristic above the carrier and a corresponding width of spectrum below the carrier. This characteristic and the width of the vestigial sideband may be measured with an oscillator and decibel meter or scope, taking care to provide the same input and output termination impedances to the portion measured as would prevail in normal transmission. This may require some measurement improvisation where the filters are not separate units but are built into the facsimile transmitter (or transmitter and receiver). The vestigial sideband is usually considered to extend from the carrier to that frequency at which the signal amplitude is down a specified amount from the amplitude at the carrier frequency. For example, in documentary and map transmission systems the edge of the vestigial band may be considered to be that frequency at which the signal amplitude is illustratively some 10 percent of that at the carrier frequency (20 dB down).

BASIC TEST: Tests may be made on the emitted vestigial sideband signal. In general the principal item of interest is the degree of reduction of the vestigial band. Based on the near identity of the two sidebands when originally generated, one can conceive of measuring the ratio, at given frequency separations from the carrier above and below, of the emitted intensities. To obtain an over-all effect, where the filter is divided into two, it is desirable to measure the signal past the second filter. The measurement requires a frequency analyzer and repeated coverings of the same matter in the subject copy, once with the analyzer adjusted for the upper sideband, and once again with it adjusted for the lower sideband. The ratio of the readings, converted into decibels, gives the attenuation of the vestigial band. One can conceive of taking the ratio with an accurate ratio detector, using two frequency analyzers simultaneously adjusted to frequencies equally spaced from the carrier. This requires only one covering of the subject copy, but considerable special apparatus.

Such tests are very cumbersome, and it is usual to measure only the component filters which attenuate and form the vestigial band. As has been already mentioned, it is important in such cases to be sure that the influence of the filter terminations as actually used is correctly reflected in the separate measurements of the filters.

1.6 *Transmission Measurements Within Facsimile Terminals*

Techniques for measuring amplitude-frequency characteristics are generally similar to those outlined under paragraph 3.1, with additional precautions.

Particular precaution must be exercised when measuring high-impedance circuits such as vacuum-tube input circuits. Care must also be taken, in some instances, to isolate alternating-current oscillators and measuring devices so that their low impedance direct-current paths do not alter or destroy facsimile circuit operation. This is particularly important in low-level semiconductor circuits.

Measurements conducted in the transmitter circuits are often invalidated due to presence of facsimile carrier either interfering or beating with the test tone. In these cases it is advisable to temporarily disable the carrier oscillator.

Great care must be observed, when measuring low level stages, to preclude hum interference or stray pickup. It is generally advisable to use shielded test leads. Ground loops, circulating grounds and hum induction from test equipment must be avoided.

1.7 *Compatibility Between Transmitter and Receiver*

To be compatible a facsimile transmitter and receiver must meet certain physical and electrical requirements. For some of these requirements 100 percent compliance is required or the recorded copy will be excessively degraded or useless. In others a degree of tolerance is permitted which is very slight for some requirements and quite generous for others and for several requirements the tolerance permissible will depend also upon the end use of the recorded copy. In the following paragraphs compatibility requirements are listed and where test procedures appear necessary to determine if the requirements are met these test procedures are provided or a reference given.

1.7.1 *Physical Requirements*

1) The recorder must provide the same number of recording spots as there are scanning spots at the scanner and in the same geometrical configuration. Multispot equipments are rare and easily identified by visual inspection. They are not to be confused with scanners employing multiple optical systems or multistyli (or generally multimarking point) recorders in which only one optical system views the subject copy at any time and only one stylus or marking point marks the record sheet at any time. The latter are all single-spot equipments and neither the number of optical systems nor the number of marking points has any bearing on their compatibility.

2) The recording spot (or spots) must trace the same pattern on the record sheet that the scanning spot (or spots) traces on the subject copy. For example, if the scanning spot starts at the upper left corner of the subject copy, moves from left to right across the copy line by line concluding at the lower right corner then the recording spot must move across the record sheet from left to right and top to bottom in precisely the same manner. However, if there is a transfer involved in the recording process which would introduce a left-right reversal in the copy, such as for example when recording on photographic film from which a contact print is to be made, the motion of the recording spot across the record sheet must be in the opposite direction from that of the scanning spot in order to preserve the correct left-right relationship in the final print. If the scanner generates picture signals in both the left-to-right and right-to-left directions which are intended to be used then the recorder must provide the same motion of the recording spot to be fully compatible.

3) If the motion of the scanning spot within the available line of the scanner is at a uniform rate the motion of the recording spot within the available line of the recorder must also be at a uniform rate. If the motion of the scanning spot is at a nonuniform rate then the motion of the recording spot must follow the same pattern of nonuniformity. Failure to meet this requirement will introduce a distortion in the received copy (see 2.3.2 Stagger).

4) If the equipment is to be used for the transmission of maps or drawings from which distances or dimensions are to be scaled or several recordings fitted together to form a single larger map, for example, the ratio between the scanning line length and the corresponding recording line length must be constant within quite close tolerances (see 1.1.1 Scanning Line Length). Likewise indices of cooperation must be closely the same (see 1.7.1.1).

5) The available line of the recorder (see 1.1.2.2 Recorder) must exceed the available line of the scanner (see 1.1.2.1 Scanner) by the amount of phasing error (see 2.2.5 Phasing Deviation) and the amount of skew (see 2.3.1 Skew) which are present. Failure to meet this requirement will result in loss or mutilation of intelligence near the left or right edges of the subject copy. In systems where a reduction or enlargement takes place the measurements involved in this requirement must be adjusted accordingly.

6) If the recorder is not of the continuous-web type the recorder line-feed mechanism must be capable of a maximum travel equal to or greater than that of the scanner (see 1.1.3 Useable Length of Copy in Noncontinuous Components). Failure to meet this requirement will result in loss or mutilation of intelligence near the bottom of the subject copy. Measurements involved in this requirement must be adjusted accordingly if a reduction or enlargement takes place.

7) The scanner and recorder must have the same stroke speed. The tolerance permitted in this requirement is extremely small (see 2.3.1 Skew). If this requirement is not met, some portion of the original information will be lost; the equivalent line recording time must be provided at the recorder to correspond to the line scanning time at the transmitter.

1.7.1.1 *Index of Cooperation, Scanning or Recording Line*

In IEEE 168 this is defined, in terms of the scanning or recording line, as the product of the total length of a scanning or recording line, in inches (or centimeters), and the number of scanning or recording nominal line widths per inch (or centimeter). It is important where transmitter and receiver are of different makes. Where the indices of cooperation of the two differ, the aspect ratio of picture features in the recorded copy will differ from the aspect ratio of these features in the subject copy (see 2.1 Index of Cooperation Distortion).

Test procedures for the measurement of the scanning or recording line length are given in Section 1.1 Dimensional and Speed Specification of Copy. Test procedures for the measurement of nominal line width of scanning or recording lines are given in Section 1.2 Fine Structure of Copy. The procedure is therefore simply to divide the first by the second.

In IEEE 168 it is noted that the index of cooperation can also be given in terms of a drum diameter (real in some machines, merely conceptual in others). It is then called the "International Index of Cooperation (CCITT)", and is equal to the scanning or recording line index of cooperation, divided by π. This of course requires no change in the test procedure.

1.7.2 *Electrical Requirements*

1.7.2.1 *Both Devices Amplitude Modulated*

If both machines use amplitude modulation, the following additional characteristics must be the same if they are to work compatibly:

1) The two must both use either black transmission or white transmission.

2) The frequency bands occupied by the signal must be approximately the same.

a) The transmitter carrier must be accepted by the receiver.

b) The transmitted sidebands must be sufficiently accepted by the receiver to reproduce a picture adequately.

c) A test for whether these conditions are met may be combined with a test for item 3), which involves transmission of the IEEE test chart using the machines back to back. Patterns to be noted particularly would be numbers 7, 8, 9, 11, 12, 13, 14, 15 and 17. These patterns must be reproduced with a fidelity which is considered adequate for the service contemplated.

3) The contrast range in the two machines must be equal or at least similar. For black and white subject copy the permissible latitude is greater than where intermediate halftones are included. The test to check compatibility in contrast range is to transmit the standard IEEE test chart with the machines back to back, and note the reproduction of pattern 14 for black and white copy and patterns 7, 8, and 15 for copy including intermediate halftones. The reproduction of these must be adequate for the service contemplated.

1.7.2.2 *Both Devices Frequency Modulated*

If both machines use frequency modulation, the following characteristics have to be the same:

1) The extremes of the frequency swing, respectively for black and white in the subject copy, must be the same.

2) The frequency bands occupied by the signal must be approximately the same.

3) The linearity of deviation must be properly related. For example, in both transmitter and receiver, frequency deviation may vary linearly with contrast of original and recorded copies or frequency deviation may vary linearly with voltage generated within a transmitter and with resultant voltage within a recorder. Differences in these relationships may be introduced purposely to correct for differences in contrast characteristics between scanning and recording techniques.

A test for whether these conditions are met is, as in the amplitude modulation case, to transmit the IEEE test chart. The reproduction of the patterns should then be noted.

1.7.3 *Auxiliary Signals and Conditions*

Facsimile machines generally use auxiliary signals such as start signals, phasing signals, end of message signals, level indicating signals, etc. These must be compatible between the transmitter and receiver to the extent that they are to be used. These signal types are varied enough that no general tests can be specified for them in advance, and it is merely necessary that the operator check the compatibility involved in each case.

It is also necessary for such simple conditions to be met as the record copy capacity being sufficient to include all that will be transmitted of the subject copy, that automatic feed features can be handled, etc. It is hardly feasible to specify general test procedures for these.

2. DISTORTIONS FROM FACSIMILE EQUIPMENT

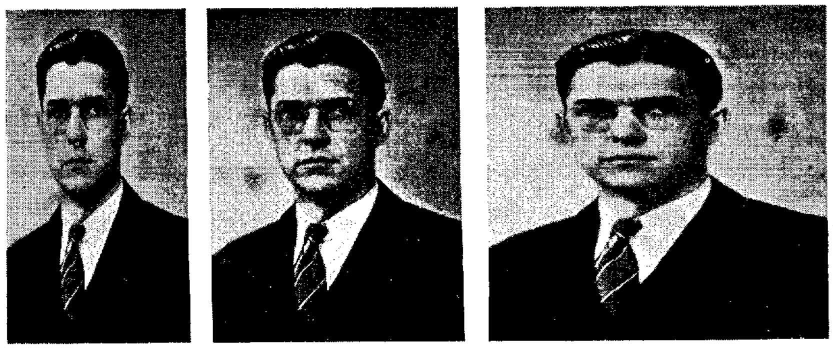
2.1 *Index of Cooperation Distortion*

The distortion that exists in the record copy due to the wrong index is called the "index of cooperation distortion." It is a compression or expansion of one or both dimensions out of proportion to the transmitted original subject copy. (see 1.7.1 Index of Cooperation.) Visual inspection of the copy will often reveal the distortion, where line advance gear settings or other adjustments are obviously incorrect.

BASIC TEST: More exact measurements can be made on pattern number 10 of the IEEE test chart. The distortion is measured as a variation in the ratio of the lengths of the horizontal to vertical lines in this pattern, from subject copy to record copy.

There is some tolerance in the index of cooperation between two machines. For example, one can say that for certain uses, if the indices are within five percent, pictures can be exchanged between them, so far as proportion is concerned. There may, however, be an effect of reduction or enlargement in the actual size of the pictures.

Figures 16 (a) and (c) are examples of transmission between two machines with indices of cooperation of 352 and 264. In Figure 16 (b) both indices are 264 and the received picture is correctly proportioned.



a b c

International Indices of Cooperation
FIGURE 16

2.2 *Errors in Spot Sizes and Placing*

At the scanner, the principal possible error in spot size is its Y dimension, which may be greater or less than the nominal line width. The same holds at the recorder, and because of this these two are considered first. At the recorder, with systems in which the spot signal is pulsed rather than continuous, successive recorded spots may be more or less distant along the scanning line than the spot X dimension, and hence show underlap or overlap. This is considered next. Other possible errors in spot placement are then treated.

2.2.1 *Scanner—Overlap and Underlap Y*

Overlap Y is defined (by extension, as the quantity is not considered for the scanner in the 1956 Definitions of Terms) as the difference between the scanning spot Y dimension and the nominal line width. It is common to express it as a fraction of the nominal line width. Where the quantity is negative one has underlap. Excessive overlap at the scanner reduces the resolving power of the facsimile system in the y direction. Excessive underlap at the scanner tends to increase the breaks caused by discrete scanning lines on fine lines in the copy that are nearly but not quite parallel to the scanning lines.

BASIC TEST: The test procedure consists in measuring the scanning spot Y dimension as described in 1.2.1.1.2, and the nominal line width in 1.2.2; and subtracting the latter from the former.

The scanning spot Y dimension is usually difficult to determine with a high degree of accuracy, and the proportionate uncertainty becomes even greater when the nominal line width is subtracted from it. However, since the resulting impairments are not really significant until the error is relatively substantial, the procedure is generally adequate.

2.2.2 *Recorder—Overlap and Underlap Y*

The definition parallels that for the scanner, and the effects of excessive error are much the same. However, an additional impairment appears at the recorder, for even a moderate error. This is an enhancement of the scanning line structure, which is most conspicuous in the intermediate grays.

BASIC TEST: The primary test procedure parallels that for the scanner, and consists in measuring the recorded spot Y dimension (1.2.1.2.2) and the nominal line width (1.2.2); then subtracting the latter from the former.

Again, the matter of accuracy is a problem when the overlap or underlap is small. If the spots are sharp enough, a secondary test procedure consists in examining the record copy, particularly in regions of intermediate gray, with a suitable microscope. The overlap or underlap can then be estimated as a fraction of the nominal line width.

Where spots are not sharp enough, test recorded copies may be made on another machine which permits controlled conditions with sharp spots, on a medium gray field. These test copies can be compared visually with the record copy under examination. If the test copies are calibrated the effective overlap or underlap may be estimated. Or the test copies may be used as limit copies to assess the acceptability of the copy under examination.

Where the copy under test shows spots that are distinctly blurred, the visual examination may give different results according to the viewing distance used. In such cases the concepts of overlap and underlap necessarily lose some of their significance.

2.2.3 *Recorder—Overlap and Underlap X*

As noted above this applies only to systems where a constant density in the subject copy is recorded as a pulsed succession of discrete recorded spots. Even in this case, it loses significance where the recorded spots themselves show, each, a conspicuous internal structure, say as conspicuous as the structure caused by the overlap or underlap.

BASIC TEST: The test procedure, where the measured quantity is significant, consists first in measuring the recorded spot X dimension. The actual distance between recorded spots is then obtained by measuring the recorded spot speed (1.1.5), and dividing this by the spot pulsing repetition rate. If this last is not known from the design of the machine it may be measured with a frequency counter. The overlap or underlap is obtained by subtracting the distance between recorded spots from the recorded spot X dimension.

Where this procedure is not accurate enough the secondary procedures described in 2.2.2 above may be resorted to, using either a microscope or sample test recorded copies.

2.2.4 *Grouping*

As defined in the 1956 Definitions of Terms this defect consists of periodic error in the spacing of recorded lines. It causes a periodic variation in underlap or overlap. A very small variation is visually noticeable when the number of recording lines per inch is 100 (or 40 per centimeter) or less. The effect of grouping on the intelligence of the recorded copy is usually negligible, but it does tend to cause objectionable deterioration of the over-all copy appearance, particularly in intermediate grays.

BASIC TEST: Since this effect is subjective the primary test procedure consists in preparing limit test copies under controlled conditions on flat intermediate gray fields. These are then visually compared with the copy from the system under examination, to assess its acceptability.

If the scanning lines are sharply enough defined in the recorded copy, a secondary test procedure consists in measuring the variations in underlap or overlap with a microscope as noted in 2.2.2. However this is rarely feasible even with photographic recordings.

2.2.5 *Phasing Deviation*

Phasing deviation is the amount by which the recorded picture is displaced along the scanning line.

BASIC TEST: It is measured by noting the displacement of any convenient straight edge perpendicular to the scanning line between the recorded copy and the subject copy after the edges of the subject copy and the record medium have been aligned.

Allowance is made for some phasing deviation in most facsimile systems. If the deviation is sufficiently great, part of the received copy may be lost. The deviation is set up so that some predetermined margin exists against such loss of any received copy. If the ends of the available scanning line appear on the page of the record medium (therefore with copy on either side of the space between these ends) the result is referred to as a "split picture" or "split copy."

2.3 *Synchronizing Errors*

Synchronizing errors result from failure to maintain a predetermined speed relationship between the scanning spot and the recorded spot within each scanning line, or from scanning line to scanning line. The resulting error can be classified in three general categories depending upon whether it is random in nature or periodic, whether it follows a similar pattern in successive scanning lines, and whether it is cumulative. The three categories are skew, stagger, and jitter, and each is treated separately below.

The distortions are in some measure additive and therefore the amount that can be tolerated from some of the errors may depend upon the amount of the others present. Since the effects are subjective and depend upon the opinion of the user, limit copies as mentioned in Drive Pattern, 2.3.3 may be used.

A simple test can be made to determine the magnitude of synchronizing errors by the use of IEEE test pattern number 10, and making certain measurements on the recorded copy.

BASIC TEST: A more comprehensive test is to transmit a sheet of cross-section paper (preferably one having blank lines such as Keuffel & Esser #358-15K, or Dietzgen #359), because this shows more samples of the errors. If precise measurement is required, consideration should be given to shrinkage of the record sheet (in humidified-paper recordings) and distortions due to photographic processing.

Synchronizing errors may be caused by either the transmitter or the receiver, or both. A transmitter and receiver of known performance may be alternately substituted for the transmitter and receiver under test to determine what portion of the total distortion is to be attributed to each of the machines involved.

2.3.1 *Skew*

Skew results when the synchronizing error is cumulative in successive scanning lines, over a substantial period, such as the duration of transmission of a picture.

In many commercial systems, synchronization is controlled by a locally generated synchronizing frequency at each terminal. The stability at each end of the circuit must be maintained within fairly close limits, or the copy will skew or slant to the right or left.

BASIC TEST: To measure skew on a recording of the IEEE test chart or of a sheet of cross-section paper, first draw a straight reference line through one of the recorded nominally vertical lines, such as, for example, one edge of pattern 10 of the test chart. This straight reference line should follow the trend of the recorded line, deviations of the recorded line being substantially equal on both sides of the reference line. Next draw a truly vertical line, perpendicular to one of the recorded horizontal lines. The skew is then expressed numerically as the tangent of the angle of slant. It can also be expressed as a slope, i.e. 1/10 inch displacement in ten inches of picture length (or 1 millimeter displacement in 10 centimeters picture length), or 0.01.

A skew of the above magnitude in a system with a total line length of 10 inches and an index of cooperation of 1000 (international index approximately 352) corresponds to a speed (or oscillator frequency) tolerance of 1 part in 100,000. Thus synchronizing frequency tolerances are fairly severe. A detailed analysis of the frequency measurement problem is given under 1.1.4 "Stroke Speed."

2.3.2 *Stagger*

Stagger results when the synchronizing error is periodic in nature and follows a pattern which is repeated in many successive scanning lines (say throughout a picture). It can result from a variety of causes. The variations manifest themselves as one or more vertical or diagonal strips along the length of the recorded copy within which characters or picture features are reproduced narrower than they should be, and other vertical strips within which they are wider than they should be.

BASIC TEST: Stagger can be measured by transmitting pattern 19 of the IEEE test chart with transmitter line feed stopped, or a sheet of cross-section paper. The spacing of the recorded lines can then be measured in the affected areas and the deviation of these measurements from the nominal is a measure of the amount of stagger. (In the presence of jitter and other distortions straight reference lines may have to be drawn through the recorded vertical lines and the spacing of these reference lines measured.) The amount of stagger is expressed as a percentage deviation from nominal, and the maximum deviations in both positive and negative directions are to be measured since they are not necessarily equal.

An illustration in Figure 17 shows examples of measurements of an exaggerated stagger having a repetition rate of one cycle per scanning line. Similar measurements would apply to stagger of higher repetition rates as well. In this case it is assumed that the line feeds of both transmitter and recorder are uniform, that a single straight diagonal line can be transmitted, and that the deviation of the recorded line from linearity serves as measurement. Using the trigonometric function noted for the angle of the line, the amount of stagger can be calculated as shown.

2.3.3 *Drive Pattern* (*Gear Pattern*)

Drive or gear pattern is an attenuated form of stagger. It shows up as a small change of density of the recorded copy and is most particularly noticeable in photographic recordings. Measurement of the pattern using a densitometer can show such a small change between the maximum and minimum density areas that it is substantially imperceptible even when the overall pattern itself is readily visible. Gear pattern can readily be detected visually in recorded bar patterns when vertical lines and spaces are of the order of 20 percent wider than the scanning spot x dimension. (In some systems that record in the form of individual recorded spots, it will be necessary for the measuring area of the densitometer to include a sufficient number of the spots to obtain a suitable average density). Drive pattern can be distinguished from hum by changing stroke speed slightly. This changes hum pattern but not drive pattern.

BASIC TEST: The usual way of evaluating this pattern is to compare recorded copy from a uniform signal, over a fair-sized area, with a sample limit copy that is agreed upon by the user as meeting his requirements. Close photographic control is required if the results are expected to be reproducible. In order to establish the limits, it is usually necessary to have some sample copy which is just acceptable, and also some sample copy which is just beyond the limits of acceptability. See Figure 18.

2.3.4 *Jitter*

Jitter results when the synchronizing error does not follow a similar pattern in successive scanning lines but is either random in nature or follows a short-term period which is not cumulative beyond a few scanning lines. It can have a variety of causes, usually within

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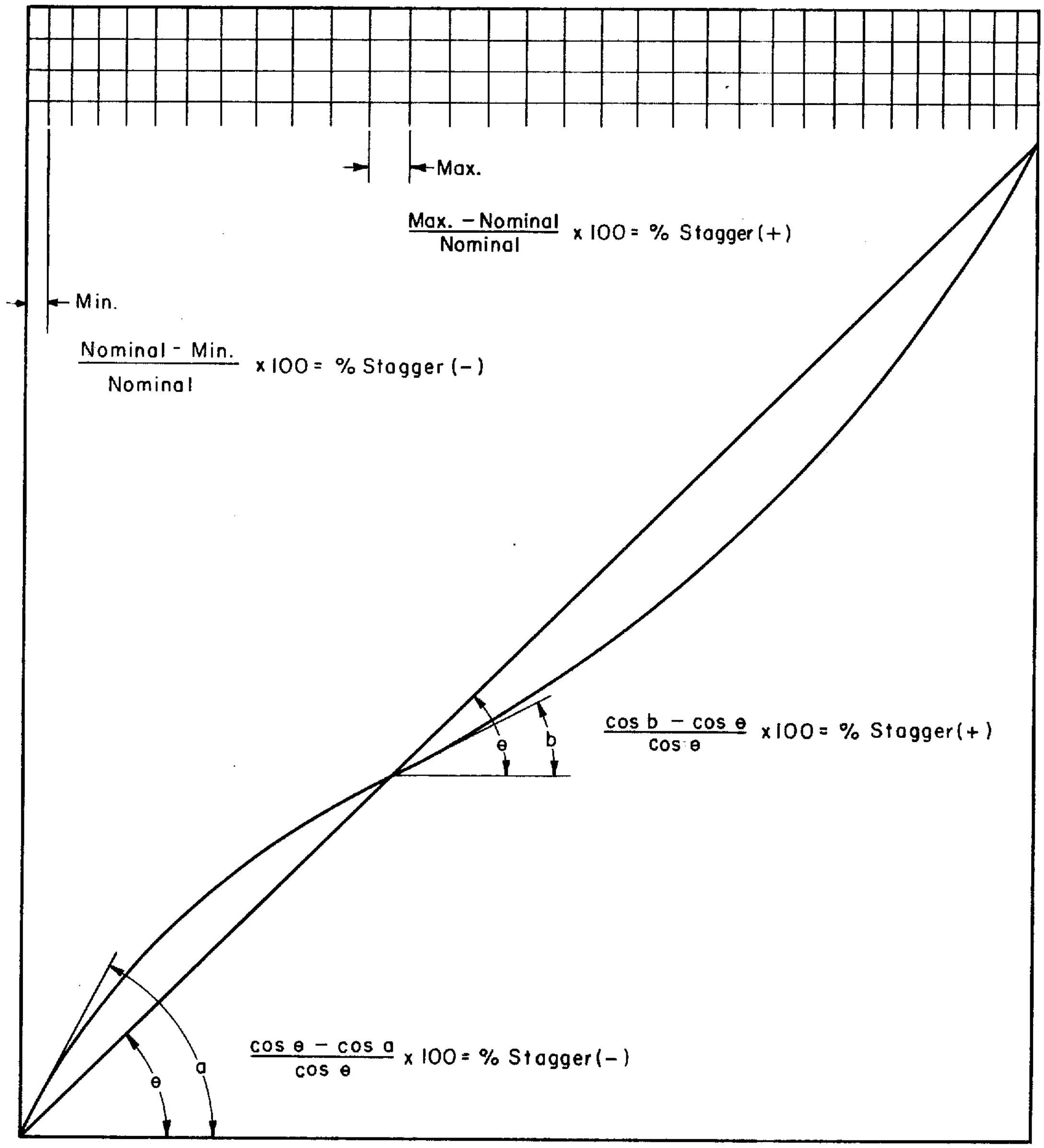


FIGURE 17. STAGGER

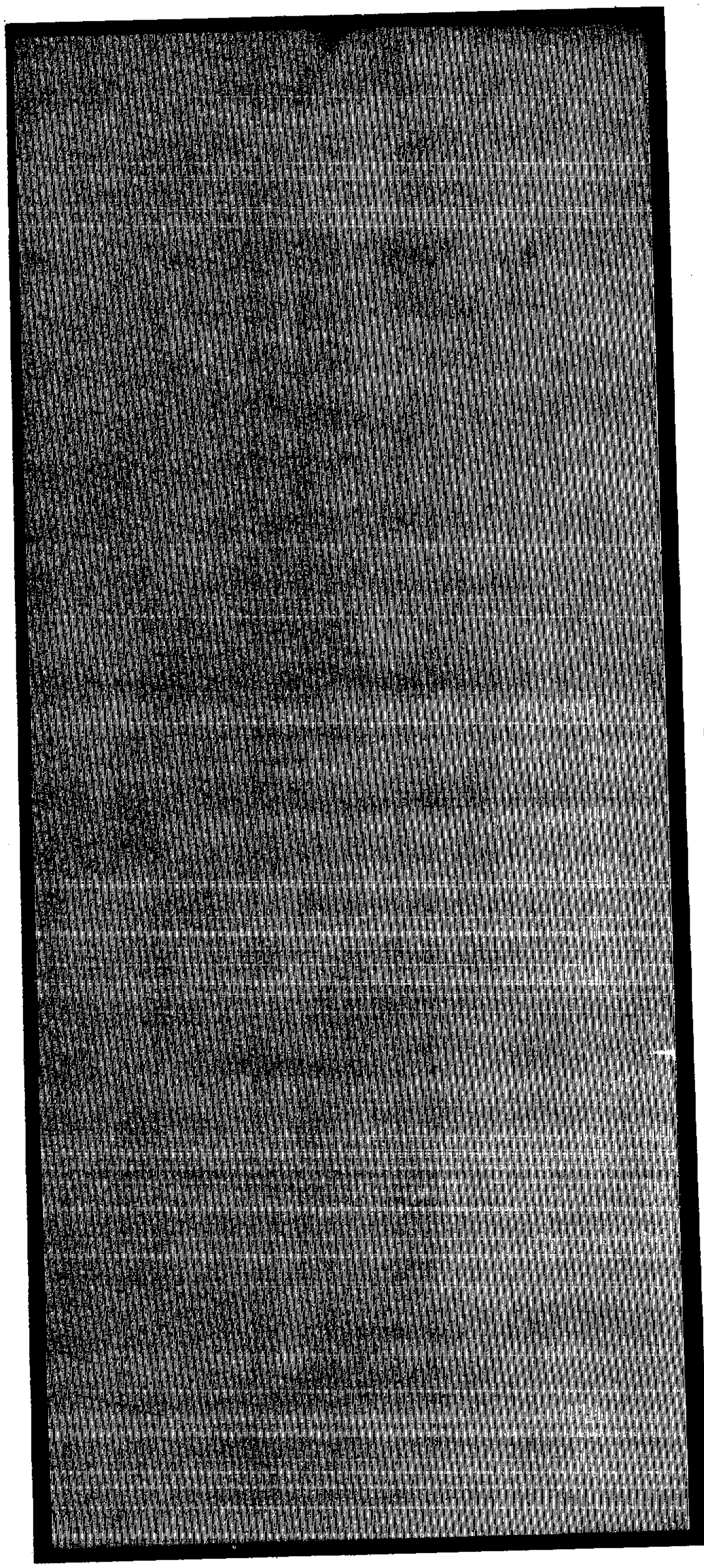


FIGURE 18. GEAR PATTERN

the facsimile equipment. Jitter can also result from random or short-term periodic variations in propagation time of the facsimile signals as in multipath transmission (see 3.3.4).

Exact measurements of the amount of jitter are generally difficult to make since the edge of the recorded spot usually is not sharp. However, to measure it, any vertical line pattern (such as pattern 19) of the IEEE test chart, or for a more comprehensive test a sheet of cross-section paper, is transmitted through the system. The record appears (shown enlarged) as in Figure 19. A reference line is drawn (as

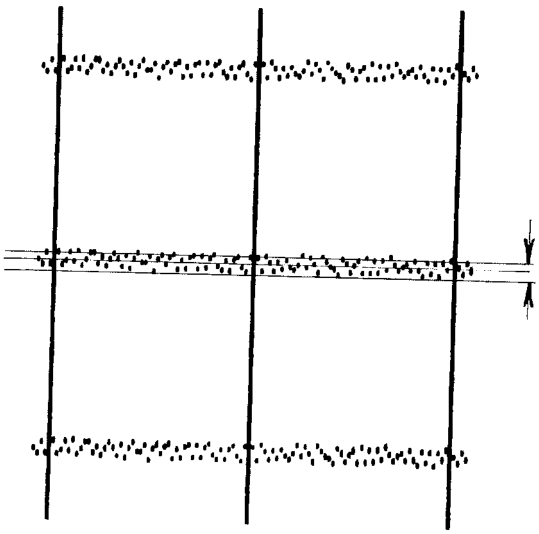


FIGURE 19

in skew, above) lengthwise through one of the recorded nominally vertical lines. This reference line follows the trend of the recorded line, deviations of the recorded line being substantially equal on both sides of the reference line. A straight line is then drawn parallel to the reference line, through the leading edge of the earliest mark comprising the recorded line. If the recorded line is of sufficient length to have recorded repetitions of this maximum deviation, then the reference line will also pass through the front edge of all such repetitions. Next, draw a reference line through the leading edge of the latest corresponding mark comprising the recorded line and parallel to the central reference line. This last line likewise will pass through the leading edge of other late marks if the record is of sufficient length. The horizontal distance between the two outer parallel lines is a measure of peak-to-peak jitter. It is then to be expressed in units of nominal line width (see 1.2.2).

BASIC TEST: In many cases the magnitude of the jitter is so small that the procedure outlined above is not practicable unless the record is magnified. In these cases a portion of the recording containing maximum jitter is mounted in a microscope so that a section of a nominally vertical line is observed using a calibrated screw micrometer eyepiece. The eyepiece is rotated so that one line of the cross hair follows the trend of the recorded line as does the center line of Figure 19. The micrometer screw is then rotated until the cross-hair line just touches the leading edge of the earliest marks and the reading noted. Then the screw is rotated until the cross-hair line just touches the leading edge of the latest marks and the reading noted. The difference between these two readings is the peak-to-peak jitter. In systems which have a steadily observed normal line position jitter is measured as the maximum displacement from this position and designated as peak-to-normal jitter.

The above procedure covers the measurement of over-all system jitter. Jitter of the receiver only may be measured using as a signal repetitive sharp pulses synchronous with the drive clock and performing the measurements outlined above on the resulting recorded lines. Jitter of the transmitter only may be measured by scanning a sheet of cross-section paper or Pattern 19 of the IEEE test chart (as before) and viewing the signal on an oscilloscope whose sweep is synchronized with the drive clock. The sweep magnification may be adjusted for convenient viewing and calibration to facilitate measurement.

3. DISTORTIONS FROM TRANSMISSION MEDIUM

3.1 *Amplitude-Frequency Characteristics*

In general the measurements described below are similar to those which would be employed in evaluating other communications media. Since facsimile reception is generally more sensitive to gain-frequency irregularities it is felt necessary to outline, in some detail, the suggested measuring techniques along with some precautions.

Ideally, a flat amplitude-frequency response is usually sought over the band of frequencies transmitted (either baseband or modulated band, depending upon the particular facsimile system).

BASIC TEST: Measurements are typically made by transmitting steady sine-wave power at the facility sending end and measuring the magnitude of the received tone with volume unit, vacuum tube voltmeter or oscilloscope instruments.

Some caution should be exercised in choosing the points in the transmission medium between which measurements are to be conducted. It is customary to measure between nominal flat-gain points (i.e. points between which amplitude-frequency equalization has been effected). Appropriate corrections must be made where pre or post amplitude equalizers have been omitted between the points of measurement.

At the sending end care must be taken to properly match the impedance of the oscillator to that of the transmission medium. This can be accomplished by employing minimum loss pads or matching transformers.

When the oscillator and transmission medium have unlike terminations (e.g. balanced-unbalanced, unbalanced-balanced, ungrounded-center tap grounded, etc.) it is usually necessary to employ a coupling transformer, even if the impedances are identical.

Unless the oscillator is known to have a constant voltage (or power) output across the band of frequencies to be measured, it will be necessary to adjust the oscillator output to some reference level across a resistance load equivalent to the nominal impedance of the transmission medium. Oscillator voltage (or power) levels should be limited to a maximum equivalent to the "Facsimile-Signal Level".

Impedance matching and coupling precautions listed previously, apply similarly at the receiving end of the transmission medium.

Measurements in the nominal audio frequency band of 20 cycles per second to 20 kilocycles per second are usually made with devices calibrated in dBm (i.e. dB with reference to one milliwatt), however, any convenient reference can be specified. Volume indicators (vu meters) and some vacuum tube voltmeters are calibrated directly in dB. Alternating voltage or current measuring devices, including oscilloscopes, can be used to measure received level in terms of volts or milliamperes root-mean-square, peak, peak-to-peak, or average values. Assuming sine-wave measurements, any of these values can be expressed as a function of any other or in terms of dB to any selected reference power or voltage.

Above 20 kilocycles per second and especially where the transmission medium is to carry quantized facsimile signals, it is customary to express measurements in terms of dBv (i.e. dB with reference to one volt peak-to-peak at some specified impedance). Otherwise the measuring techniques are essentially identical to those outlined for audio band mediums.

Having observed all of the aforementioned precautions, and having chosen a suitable measuring reference, the following technique for measuring the frequency characteristic of the transmission medium is suggested.

A reference frequency, usually near the center of the pass-band to be measured, should be selected. Amplitude measurements of frequencies different from the reference are then conveniently referred to the reference frequency amplitude in terms of dB, volts, or milliamperes deviations.

The frequency interval (spacing) between successive amplitude measurements is usually chosen to permit accurate interpolation between readings. Thus, on a fairly straight line portion of a frequency run, the frequency interval can be made rather large, however, where sharp irregularities are encountered and near the edge-of-band cutoff regions, the frequency interval should be reduced.

Convenient graphic plotting of the amplitude-frequency characteristic can be obtained with the use of semilog graph paper. Frequency is plotted along the logrithmic axis and amplitude, in terms of dB, is plotted along the linear axis.

3.2 *Phase-Frequency Characteristic*

3.2.1 *Envelope Delay Distortion*

It is necessary for the shape of the wave of a facsimile signal to be faithfully reproduced at the receiver. Thus it is just as important that there be no distortion with respect to frequency in the phase, as in the amplitude. This is in sharp distinction to telephone signal transmission, where the ear is generally insensitive to phase differences.

There is a close relationship between phase distortion and signal echoes,[12, 13] the former always leading to the latter in some form or other. In less severe cases, the resultant copy may have the appearance of any one, or a combination of "echo," "facsimile transient," "ringing," or "tailing." In more severe cases the echo is a more or less distinct displaced copy superposed on the main image.

For the undistorted transmission of a signal between two points, the steady-state phase shift between these points is proportional to frequency over the utilized frequency range.

That is, $\phi = \omega T$ (18)

where ϕ = phase shift in radians

ω = frequency in radians per second

T = phase delay in seconds

Phase-frequency distortion exists when the phase shift is some other function of frequency in the utilized range.

There are numerous methods of measuring the steady-state phase shift as a function of frequency. A preferred method, however, is to measure it indirectly through the envelope delay. This is a sensitive test, it is practical in circuits with active elements, and it has been found that deviations from it give a fair quantitative index of the facsimile picture impairment resulting from the distortion.

For the undistorted case of equation (18) the envelope delay is

$$D = d\phi/d\omega = T \qquad (19)$$

where D = envelope delay, in seconds

Thus, in the undistorted case, the envelope delay is a constant, and is equal to the phase delay.

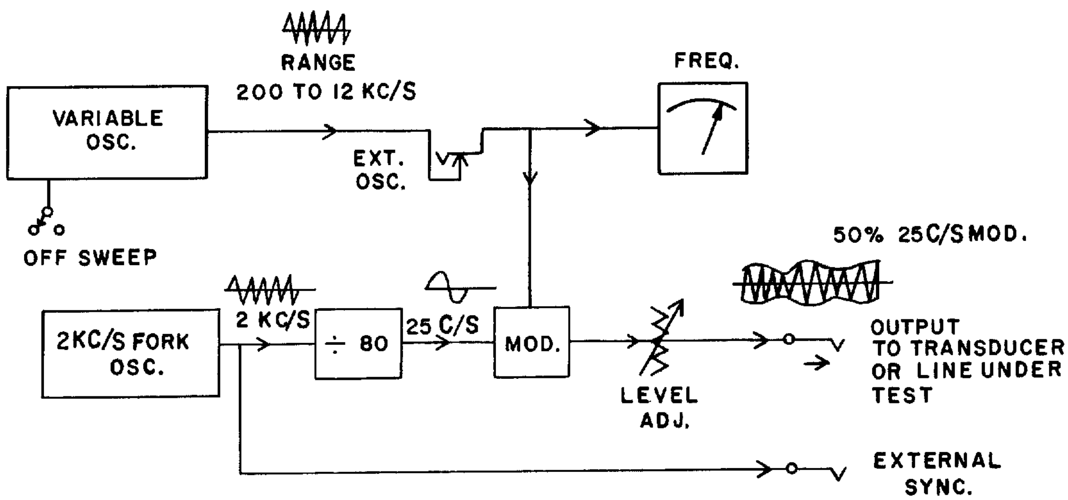
The envelope delay as defined above measures the time displacement of the modulating envelope of a carrier frequency of ω radians per second (to be exact, it is really the limit of this displacement as the baseband width of the modulation approaches zero).[14]

Envelope delay distortion is measured by the deviations of the observed envelope delay over the utilized frequency range.

3.2.1.1 *Typical Measuring System*

BASIC TEST: Conventional envelope delay measurement is carried out by modulating a variable carrier frequency wave at a transmitter with a constant low frequency (usually 25 cycles per second). The time displacement of the 25-cycle-per-second envelope is measured at a receiver as the carrier frequency is varied over the spectrum which it is desired to use, and this gives the envelope delay. When the measurement is carried out in this way over a straightaway circuit it is possible to measure only the envelope delay distortion. When the measurement is carried out over a looped circuit, so that transmitter and receiver are adjacent, it is possible to measure the actual time displacement of the envelope (or the "absolute" envelope delay).

A typical envelope delay measuring instrument[15] is illustrated in Figures 20 and 21.



BLOCK DIAGRAM
ENVELOPE DELAY MEASURING SET
TRANSMITTER
FIGURE 20

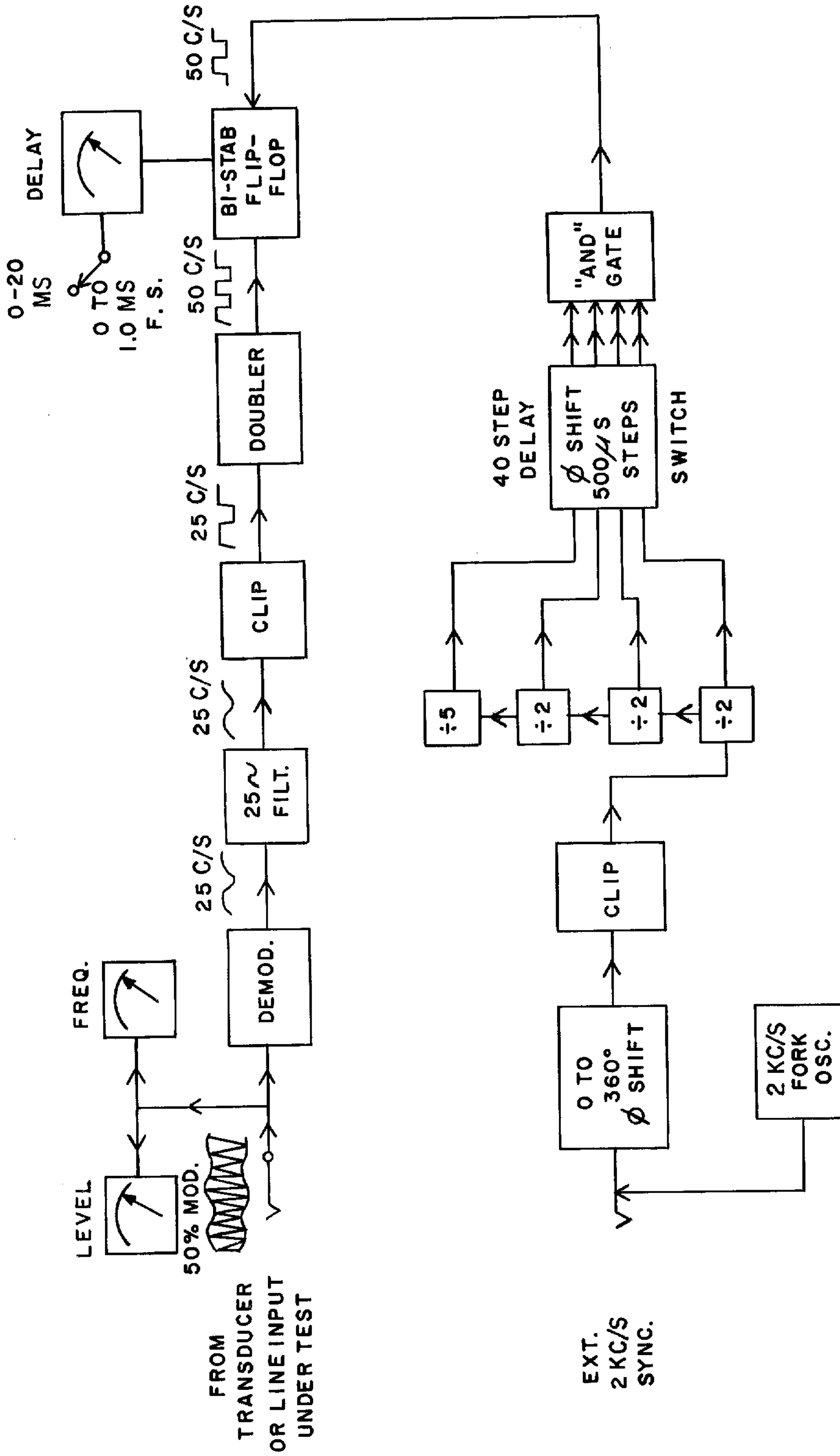
The transmitter, Figure 20, amplitude modulates any preselected frequency in the audio band. Frequency of modulation in the system depicted is 25 cycles per second, derived from a stable 2-kilocycle-per-second fork output by means of count-down circuitry (1/80). A separate 2-kilocycle-per-second fork output is provided to allow direct synchronization of the receiving delay meter.

It is the envelope delay at the preselected frequency which is measured by the delay measuring set.

At the receiver, in Figure 21, the incoming signal from the transducer being measured is demodulated to recover the 25-cycle-per-second envelope. This 25-cycle-per-second signal is then squared and doubled in frequency to 50 cycles per second.

A 50-cycle-per-second reference signal is derived from a local 2-kilocycle-per-second tuning fork oscillator located in the receiver, or, from a 2-kilocycle-per-second signal transmitted over a separate facility from the transmitter fork oscillator.

The receiver delay meter effectively mea-



BLOCK DIAGRAM
ENVELOPE DELAY MEASURING SET
RECEIVER
FIGURE 21

sures the duty cycle of a bistable multivibrator which is triggered alternately by the 50-cycle-per-second signal representing the incoming modulation envelope and the 50-cycle-per-second reference signal. The difference in phase between the two 50-cycle-per-second signals at different transmitted carrier frequencies is then a measure of the relative envelope delay of the transducer under test.

Means are provided in the receiver for adjusting the phase of the reference frequency wave either continuously or in 500 microsecond steps to allow for convenient reference phase adjustment.

The maximum delay directly measurable with the illustrative system described is equal to the period of the 50-cycle-per-second wave or:

$$10^6/50 = 20{,}000 \text{ microseconds} \qquad (20)$$

Delays greater than 20,000 microseconds can be determined; however, it is necessary to compute theoretically the number of whole multiples of twenty-thousand microseconds involved.

The 2-kilocycle-per-second transmitter reference is desirable for all straightaway delay measurements to eliminate the effects of drift between the transmitter and receiver fork oscillators. It should be noted that facilities utilized for the 2-kilocycle-per-second reference must be synchronized (some single-sideband carrier systems employed by common carriers are asynchronous—making them undesirable) or a modulating method of transmitting the 2 kilocycles per second will be necessary.

In all the foregoing, modulating, fork, and carrier frequencies are typical only. Other frequencies and details may be employed in practice.

3.2.1.2 *Straightaway Measurements—Sweep Method*

The transmitter is located at one end and the receiver at the other end of the circuit being measured. The variable oscillator at the transmitter is set at a steady frequency and the precision oscillator at the receiver is adjusted until the drift as observed on the most sensitive delay scale is a minimum. It is not essential to remove all of the drift to conduct measurements. It is only necessary that the drift be made slow enough to permit time for measurement.

The variable oscillator then is adjusted to cover an assigned portion of the spectrum, for instance from 800 to 2900 cycles per second, and a sweep rate is selected. At the receiver the 25-cycle-per-second modulated signal produces a relative delay reading on the delay meter, and the corresponding instantaneous frequency indication on the frequency meter. If desired, the delay characteristic can be displayed on an oscilloscope with the frequency indication as the horizontal axis and the delay indication as the vertical axis. The amount of delay change over the sweep band as observed on the meter or oscilloscope then is a measure of the envelope delay distortion present. Often a very fine ripple in the characteristics can be ignored.[13]

For many measurement operations, it is only necessary to sweep the oscillator continuously at the transmitter and observe the variations in delay at the receiver, and the position of variations in the frequency spectrum. In addition, delay distortion correction of the circuit can be checked by observing the effect of inserted networks to make the delay variations over the sweep range within a prescribed tolerance.

3.2.1.3 *Straightaway Measurements—Point-By-Point Method*

Often graphic plotting of delay characteristics is desirable. This is most accurately accomplished by a point-to-point method. For this purpose, a reference frequency is selected, usually 2000 cycles per second for a 3-kilocycle-per-second bandwidth circuit. To obtain readings for each frequency that is plotted, delay readings should first be taken at the reference frequency and then at the frequency which is to be plotted. The delay figure to be plotted relative to 2000 cycles per second, then, is the difference between the two readings. The readings are conveniently recorded in microseconds.

3.2.1.4 *Loop Measurements*

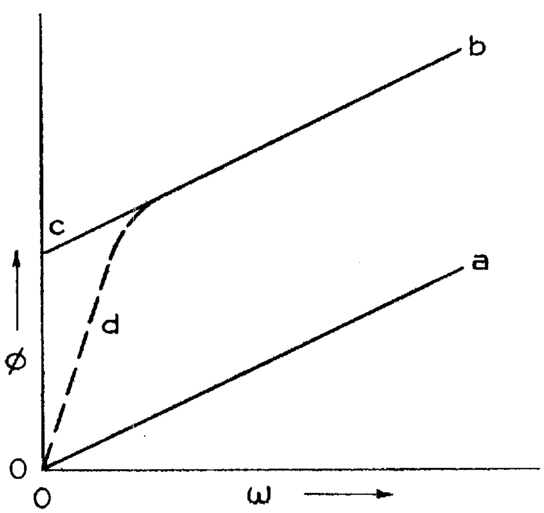
Absolute measurements can be readily made only when the circuit is a loop using a transmitter and receiver at a common location. Measurements are preferably made by a point-by-point method, since accuracy is generally an important consideration. The absolute value for each frequency to be plotted is obtained by subtracting the envelope delay of the instrument from the measured envelope delay value. The envelope delay of the instrument may be obtained by switching the transmitter output directly into the receiver input. A typical set of values is as follows:

Over-all measured envelope delay	17.55 milliseconds
Instrument envelope delay	2.32 milliseconds
Absolute envelope delay of transducer or circuit	15.23 milliseconds

It should be noted that absolute delays exceeding the period of the modulating frequency employed by the delay measuring system can be determined by a knowledge of the approximate propagation velocity and length of the circuit. Thus, for the typical delay measuring system which has been outlined above, multiples of 20,000 microseconds are computed since this is the period of the 50-cycle-per-second wave derived from the envelope.

3.2.2 *Phase Intercept Distortion*

This occurs when the phase is a linear function of frequency, but does not go through zero frequency. This is indicated in Figure 22. Here "a" represents an undistorted phase characteristic. Then "b" represents a linear characteristic which has the intercept "c" at zero frequency.



PHASE-FREQUENCY RELATIONSHIP
FIGURE 22

This is apt to occur on transmission media which cut off at zero frequency, such as series capacitance or transformers. In such cases what usually happens is that the phase shift at very low frequencies follows some such course as shown at "d". This is accompanied by a distortion in the amplitude-frequency characteristic at the corresponding very low frequencies.

When a baseband facsimile signal is transmitted over such a medium, the received image will show distortion in the form of streaks paralleling the scanning lines in the close neighborhood of picture features. This is an important reason why baseband or picture frequency transmission, at least over any appreciable distance, is rarely used for facsimile. The tests for such distortion are therefore not current. Analogous tests, however, are available in the case of "video" transmission of television, and may be adapted if allowance is made for the very great differences in spot speed and scanning line frequency. These are described in IEEE Standards on Television.[16]

There is a special case where the phase intercept "c" is a multiple of π radians. This gives no distortion from the phase intercept if the particular signal being used contains no Fourier components in the transition region indicated by "d".

When carrier transmission is used, the phase intercept involved is at the carrier frequency. That is, if only phase intercept distortion is in question, the phase shift of the medium appears as:

$$\phi = D\,(\omega - \omega_0) + \phi_0 \qquad (21)$$

where ϕ = phase shift of medium
D = envelope delay
ω = angular frequency
ω_0 = angular frequency of carrier
ϕ_0 = phase intercept at carrier

The phase displacement caused by a finite ϕ_0 brings about no distortion. Amplitude-frequency distortion and envelope delay distortion about the carrier, however (and these are likely to be accompanied by intercept distortion), generate "quadrature distortion" (see also 1.5.6—Vestigial Sideband).[17]

3.3 *Signal Distortions*

3.3.1 *Tailing (Hangover)*

"Tailing" is defined in the list of terms as excessive prolongation of the decay of the signal.

The word "excessive" is not further defined, but presumably it is meant that a decay of the order of time set by the frequency bandwidth of the channel through which the signal is transmitted (say of the order of the reciprocal of the bandwidth) would be normal. A time substantially greater than this would then be "excessive."

In a linear transmission system this phenomenon is merely another description of the presence of some form of delay and amplitude-frequency distortion in the system. In actual practice it is most likely to be delay distortion, and from general experience it is found that the most useful tests to analyze and correct it are measurements of the amplitude-frequency and phase-frequency characteristics of the system. (See 3.1, Amplitude-Frequency Characteristic, and 3.2, Phase-Frequency Characteristic.)

While most facilities expected to be used for facsimile are reasonably linear, occasionally some radically nonlinear elements may be found. An instance of these is a compandor. Compandors usually introduce some amount of "tailing", and because of the nonlinearity it cannot be usefully analyzed in terms of the amplitude or phase distortion.

BASIC TEST: In this case complete measurement of the effect requires a full oscillograph trace reproduction of the signal coming after a sharp change both from black to white and vice versa in the subject copy. The two transitions are needed because of the nonlinearity. Usually, however, a single number is significant enough to characterize the seriousness of the effect: namely the time required for the signal to decay to $1/e$ th (0.368) of its maximum value, or the corresponding rise time; whichever is worse. This gives the time constant of the decay that would be caused by a shunt capacitance in a linear system.

3.3.2 *Echo*

Echo is the term applied to a signal which has been reflected in the transmission medium (or sometimes in the apparatus) and usually arrives at the recorder later than the main signal. It can be positive or negative, i.e., blacks in the main image can reproduce respectively as blacks or whites in the duplicate. It can be sharp or diffuse.

When the displacement from the main image is very small the effect can be largely to diffuse the sharp edges of this image, or to widen lines in it, or to add fringes (having somewhat the appearance of coarse diffraction fringes) about the edges. In such a case the effect is not always recognizable as that of a distinct echo although the basic phenomenon is really the same.

When an echo is present in a given transmission path the steady-state characteristics of the path as a function of frequency are affected.[18, 19, 20] This results from the characteristics being the Fourier transform of the received signal from a transmitted impulse. For a single sharp echo the amplitude response and the phase shift (or also envelope delay) develop sinusoidal ripples whose amplitude is proportional to the echo amplitude and whose spacing is inversely proportional to the echo delay from the main signal. For a multiplicity of echoes the ripples in the characteristics cumulate to an irregular deviation from the smooth echo-free condition.

BASIC TEST: In testing, echoes may be measured by the use of an oscilloscope or oscillograph to record the received signal. Or they may be measured directly on received copy, much the way jitter is measured (see 2.3.4). It is more common to measure echo, especially when there are multiple echoes, by measuring the steady-state characteristics. This is an especially sensitive measurement in the case of the envelope delay. The envelope-delay distortion, which is expressed as plus and minus one-half the difference between the maximum and the minimum envelope delays in the utilized frequency range of the signal, is generally used as a measure of the over-all echo impairment. It is recognized that this is not always a true measurement of this impairment, but its convenience is so great that it is used nevertheless.

Consequently the testing procedures for the measurement of echo conventionally resolve themselves into the measurement of envelope delay distortion, for which refer to 3.2.1, Envelope Delay Distortion.

3.3.2.1 *Echo (for radio transmission)*

Radio transmission can well offer a variety of paths via reflections from hills, buildings, the ionosphere, etc. Since these paths are most likely of different lengths, several replicas of the signal, of different intensities, are then received at successive instants of time.[21, 22] The shortest path and therefore the first signal usually, but not always, shows the highest intensity. The multiple replicas therefore appear as echoes.

In actual practice it makes an important difference in the appearance of received copy whether the reflection comes from a stable point, such as a building, or from a varying point, such as is often observed in the ionosphere.[23, 24] In the first case successive scanning lines show the same echo delay, so that the echoes appear as displaced copies of the first image. The copies may be positive or negative, i.e., black may be copied as black, or as white. In practice, these are termed "echoes".

Where the differences in time of arrival are small the edges of sharp lines in the picture, running across the scanning lines, are blurred. Where the time differences are larger, patterns similar to diffraction fringes (or "ringing") can appear about sharp edges; and when they are still larger, the multiple images can be distinctly perceived, as in wire line transmission.

Where the echo delay is stable over a long enough period of time, the effect can be measured using envelope delay distortion measuring techniques. The measured distortion can then be compared with the usual tolerances to establish the seriousness of the echo effect in a quantitative way.

Where the echo delay is sufficiently sharp and stable and occurs on line-of-sight radio links, it may further be used to locate the probable reflection point on a map. This point will lie on an ellipse about the transmitter and receiver as foci. A simple test procedure is to make a loop of string equal in length to the sum of the direct and delayed path lengths (as measured by the difference between the respective signal delays). The distance on the copy, or the time difference on an oscilloscope or oscillograph, can be translated into a radio path difference in miles or kilometers by the equations

$$D = dc/s = tc \tag{22}$$

where D = radio path difference

d = distance of echo on record copy

c = velocity of electromagnetic waves

s = spot speed on record copy (see 1.1.5)

t = time difference = d/s

When this string is looped around pins at the transmitter and receiver on the map, a pencil moved to keep the loop open (as a triangle) and taut will draw the ellipse.

In the second case, where the phenomenon is not stable, the various signal repetitions are apt to show little correlation from one scanning line to the next, and the interference is not immediately recognizable as formed of image replicas. In this case the effect is usually called "multipath transmission," as covered immediately below.

3.3.3 *Multipath Transmission*

In the case where the reflection points, and therefore the echo delays, are not stable, the practical, and the more usual test consists merely in transmitting a critical picture (say the IEEE Test Chart) and examining the result. It is difficult in such cases to describe the effect quantitatively, but the recorded picture can be examined to determine if it is sufficiently good for the application desired.

BASIC TEST: The final signal can also be examined in an oscilloscope or oscillograph, and the nature of the multiple receptions distinguished in more detail. In such cases the emitted signal is preferably a sharp pulse, not longer in duration say than the signal coming from a fine line crossing the scanning lines in the facsimile scanner. Because the radio waves may be of varying phases, the secondary images may show as positive or negative (or may even disappear if the waves add suitably in quadrature to the main signal wave). The sent pulse is usually repeated at convenient regular intervals. If the phenomenon is unstable, this description of course varies from test to test over the same facility.

3.3.4 *Jitter*

The measurement of jitter has already been described in 2.3.4 where it is caused by defects in the equipment. It can also be caused by defects in the transmission medium. In such a case it can be measured in exactly the same way as for the equipment defects. A preliminary test is of course needed with the test equipment itself, to check the degree of jitter it contributes.

3.4 *Noise*

3.4.1 *Noise, Land Line*

3.4.1.1 *Random Noise*

Random noise appears in the received copy as a coarse grainy structure. In an amplitude-modulation system noise is usually more noticeable in those portions of the copy which represent low signal transmission levels.

Noise can be qualitatively analyzed in an amplitude-modulation system by copying a constant-frequency tone which is transmitted at a constant level midway (in dB) between black and white reference levels. The result is termed a "screen" and can be visually analyzed for noise impairment.

A similar arrangement is employed for analyzing noise in a frequency-modulation system. However, normal signal level is employed first at black and then at white reference frequencies. The resulting screen runs are visually inspected for a coarse grainy structure, the magnitude of which is proportional to the noise intensity.

Usually the transmission facilities account for the greater part of the recorded noise. However, screen runs depicting receiver noise can be made by applying tone directly to the receiver input.

BASIC TEST: Quantitatively, random noise can be measured with a noise measuring device (consisting of a rectifier feeding into a meter which usually has ballistic constants that tend, at least to a degree, to smooth out the readings with time). The device is preceded by a suitable weighting network to restrict the measured frequency band to that corresponding to the one over which the facsimile signals are transmitted.

At present not enough is known about the relative effects on facsimile transmission of noise energy at different frequencies to recommend special weighting networks for facsimile testing; in any case, different weighting networks would presumably be required for frequency-modulation and amplitude-modulation systems.

For testing voice-frequency transmission facilities, it is convenient to use the weighting networks that are conventionally used in telephony—"C-Message" weighting in the United States (with which there has been experience in facsimile transmission measurements) and CCITT psophometric weighting in most other countries. Measurement with one or the other of these networks, as available, is therefore the recommended basic test. The response of the C-Message weighting network is given in Table 1, and in Figure 23.

Random noise measurements can be made (and the results should be essentially the

C – MESSAGE CHARACTERISTIC

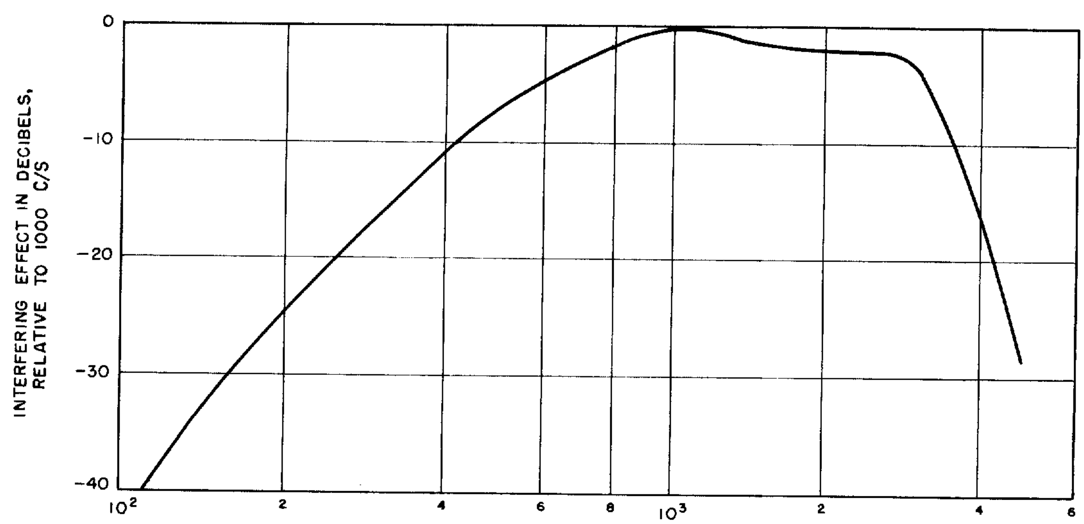


FIGURE 23

same) with a standard vu meter provided that suitable frequency weighting is employed ahead of the instrument.

Figure 24 illustrates facsimile copy transmitted over facilities having a high random noise level.

FIGURE 24. RANDOM NOISE

FIGURE 25. IMPULSE NOISE

FIGURE 26. SINGLE-FREQUENCY NOISE

TABLE 1
Frequency Response of "Message-C" Noise Weighting

Frequency c/s	Level in dB Referred to the 1000 c/s level
110	—40
200	—25
300	—17
400	—12
500	—7.5
600	—5
800	—1
1000	0 *
1500	—1
2000	—1.5
3000	—4
4000	—17
5000	—28

* Reference = —90 dBm

3.4.1.2 *Impulse Noise*

Impulse noise caused by static discharge, relay transients, electric power devices, and teletype crosstalk usually appears as sharp dots or streaks of short duration in received copy. Usually, unless severe, this type of noise does not cause serious impairment to facsimile copy.

BASIC TEST: Impulse noise can be measured with an oscilloscope calibrated to read peak-to-peak voltage. Peak-reading voltmeters or "impact meters" can be employed to measure peak noise directly in dB above a reference. Noise measurements are usually made with no signal applied at the transmitting end, but with input normally terminated.

Peak noise limits for a particular system must be determined experimentally, since each system will react differently to the same measured noise.

Figure 25 shows the result of impulse noise occurring during picture transmission.

3.4.1.3 *Single-frequency noise*

Single-frequency noise can cause objectionable beat patterns in received facsimile copy. It can enter the facsimile system in two typical ways. First it can enter at baseband frequency in the baseband signal, either at the transmitter or receiver. In such a case the interfering tone (or hum) can be determined by counting the number of interfering dark or light bands intersecting a scanning line, per inch, and applying the following formula:

(1) Interfering frequency = (Number of interfering bands per unit length) × (Receiver spot speed in unit lengths per second).

Secondly for a system employing carrier transmission, the noise can enter in the line signal, especially in frequencies lying near the carrier. Then the frequency is:

(2) Interfering frequency in cycles per second = Carrier Frequency ± (1) above.

In a double sideband facsimile system the interfering frequency can be any one of the three computed frequencies in (1) and (2).

BASIC TEST: A convenient method of testing for interfering frequencies in the transmission medium is to sweep the transmission band slowly with a wave analyzer during a period when no signals are being transmitted.

Single-frequency noise patterns caused by intermodulation between the picture signal and a disturbing frequency lying outside the picture frequency band can be measured, in frequency, by applying steady maximum carrier frequency at the facsimile transmitter while tuning the wave analyzer slowly through the facsimile band for sideband signals. The interfering frequency then is:

(3) Frequency of interference $= F_c - F_{sb}$

where $F_{sb} < F_c$

F_c = Carrier frequency in cycles per second

F_{sb} = Sideband frequency in cycles per second

(4) Frequency of interference $= F_{sb} - F_c$

where $F_{sb} > F_c$

With the wave analyzer tuned to the interfering frequency the noise amplitude is then measured.

As an illustration, for an amplitude-modulation facsimile system employing 30 dB contrast range, single-frequency interference lying within the frequency pass-band of the system can produce a pattern just noticeable in negative film material when the level of the interfering frequency is of the order of 40 dB below maximum carrier level.

Figure 26 illustrates a picture impaired by single-frequency tone.

3.4.2 *Noise (Radio)*

Noise is defined as any extraneous electric disturbance tending to interfere with the normal reception of a transmitted signal. For radio transmissions there are many types of disturbances such as random noise, effects of fading, spurious oscillations, inversion, and nonrandom noise such as interferences from ignition systems or hum.

The measurement of noise over radio links used for facsimile is a more difficult problem than the corresponding measurement over wire links. This is because the radio noise tends to fluctuate with time over a much wider range, on any given facility, than wire-line noise usually does.

BASIC TEST: Over microwave radio links, that are multiplexed primarily for telephone channels, the noise is measured in generally the same way that it is over any facsimile channel that uses a telephone facility. It is noted however, that there are occasional periods of extreme fading which manifest themselves as periods of high noise. The suitability of the channel for facsimile transmission is gauged in just about the same way as for wire channels; although the fluctuations, when they come, may be recognized as being more violent.

There are certain special cases of interference that call for measuring techniques different from the simple noise measurements.

Fading, multipath and the random noise level are usually interrelated. The arrival of the facsimile signals over different paths causes selective signal cancellations, signal reinforcement, modulation frequency doubling when the carriers cancel, and high noise level when the over-all signal levels are low due to cancellation. The latter is usually emphasized by automatic volume control or limiter circuits of the radio receiver. These disturbances fluctuate as the ionospheric conditions change. They are usually measured qualitatively on the received facsimile picture. In addition to the simple measurement of the noise, measuring the displacement of received dots of a line which is perpendicular to the direction of scanning and relating the displacement to recording spot speed, permits the differences in delays of the various paths to be calculated. This can give a clue to needed corrective action if it is possible.

Spurious oscillations are sometimes caused by feedback defects in the transmitter or receiver. Measurement in such cases consists of viewing the received facsimile copy for tailing.

Inversions are usually the result of improper setting of radio frequencies. For example, frequency shift radio signals are often detected through use of a beat-frequency-oscillator at the receiver. If the frequency of this oscillator is set higher than the signals when it should be lower (or vice-versa) the signals which are detected will be inverted, i.e., black level will become white level and white level black. The test procedure consists merely in noting the nature of the copy.

Nonrandom noises are usually qualitatively judged on the facsimile recording and, proceeding with the testing technique, are then traced throughout the entire circuit using an oscilloscope or audio tracing techniques. Hum, for example, may be identified on the oscilloscope as a pattern having a frequency equal to one, two, or three times power-line frequency. It may sometimes appear as a sharp small pip occurring once per power-line voltage cycle. These nonrandom noises may be related to other than power-line sources (e.g., a nearby timing circuit).

Over some radio links the range of noise variation is so great that the major question is simple feasibility of transmission, and no special techniques are generally used for facsimile as distinguished from other forms of radio communication. A great body of information has been in process of being gathered on the intensity of radio noise and its variation with locality, time of year, sunspot cycle, etc. See for example "Radio Noise Data for the International Geophysical Year, July 1, 1957—December 31, 1958", by W. Q. Crichlow, C. A. Samson, R. T. Disney and M. A. Jenkins, Technical Note No. 18, Boulder Laboratories, National Bureau of Standards. This program has been continued. Under these circumstances, there is no point to considering further different types of noise measurements for facsimile than for general radio communication.

3.4.3 *Noise Figure*

In some cases of electric signal transmission, particularly via radio, it is desirable to know the ratio of the actual noise output at a given point to that which would be contributed solely by thermal agitation of the input termination at the standard temperature of 290° Kelvin. This is known as the "Noise Figure" of the transducer between the input and output points cited. It is little used in facsimile system engineering as such (though it may be used in the primary engineering of the communication facility employed). The ratio is merely referred to here as F (and the corresponding effective noise temperature of the transducer as T_e) in IEEE Standards 160 and 161, respectively. These Standards are to be followed for facsimile test procedures that involve this concept.

3.5 *Intermodulation*

3.5.1 *Kendall Effect*

This effect comes from unwanted modulation (usually rectification) of the facsimile carrier signal in the transmitted modulated band, which generates a baseband that overlaps and interferes with the lower sideband of the carrier signal. The rectification usually occurs in the facility transmission, though it is also possible in the terminal apparatus. It frequently occurs in systems where the ratio of carrier frequency to maximum keying frequency is low, resulting in an overlap between portions of the frequency bands occupied by the modulating and modulation frequencies and especially where the modulating frequencies are not adequately suppressed in the transmitter output.

The appearance of the effect is usually in the form of a diagonal line or hairy pattern following sharp demarcations between extreme black and white in the picture. In extreme cases the effect appears as a "roping" of lines which are vertical, or nearly so, such that they appear dashed rather than continuous. Figure 27 illustrates Kendall effect between the face of the trainman and the white bar immediately in front of it.

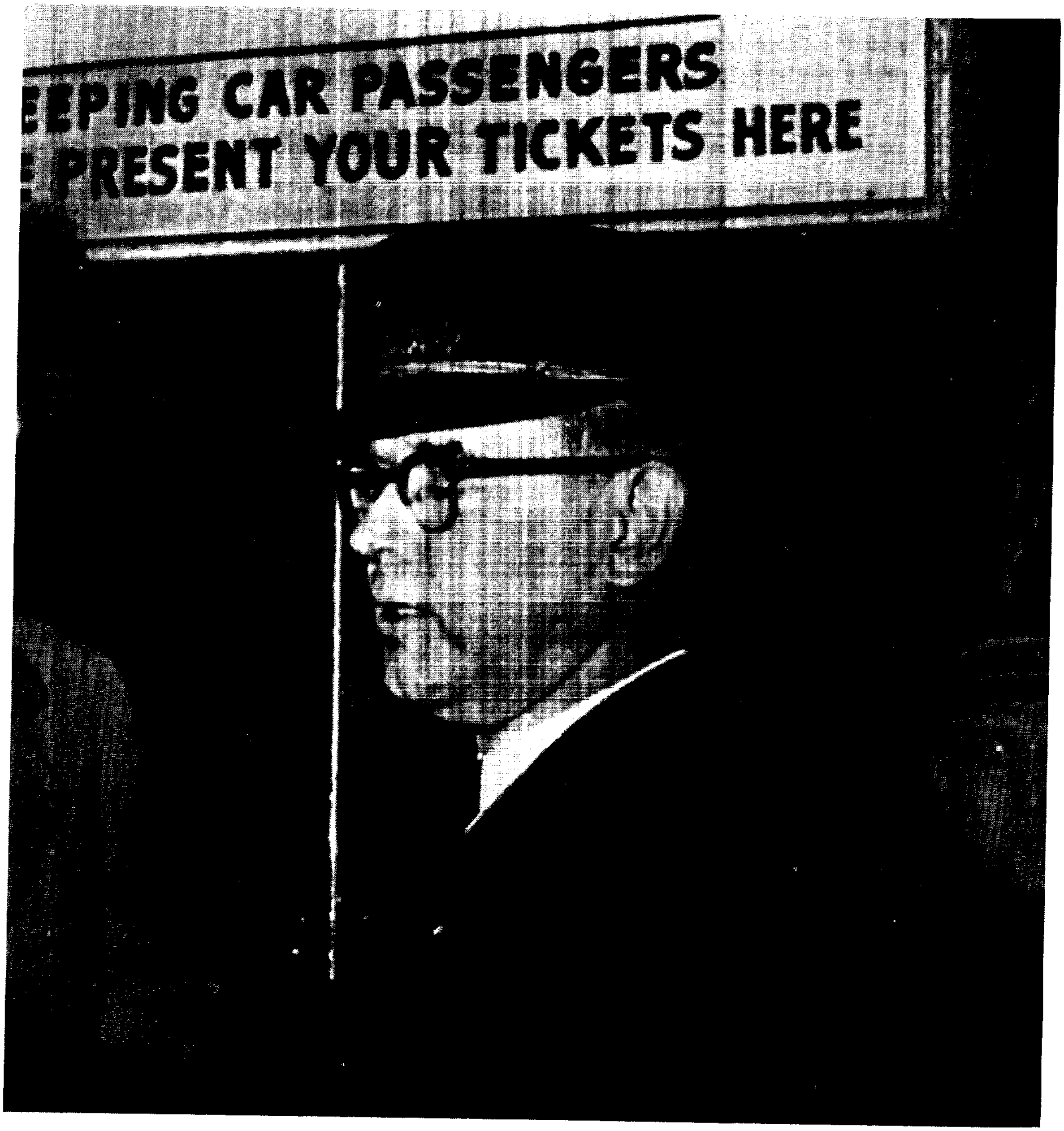


FIGURE 27. KENDALL EFFECT

The effect is not usually apparent on any but high-quality received pictures nor usually on any but long-haul transmission facilities. With present-day facilities, the modulation causing it comes mostly from modulators at terminals and intermediate drops, where the signal is transformed from voice to carrier and back.

The general experience is that tests of Kendall effect with a single strongly nonlinear device to simulate an extended line do not necessarily provide a satisfactory simulation.

In the current art it has not yet been feasible to express the Kendall effect quantitatively in numerical terms.

BASIC TEST: As a result of all these observations, tests to discover possible Kendall effect must be carried out with high-quality pictures having sharp demarcations between black and white. The test must be carried out generally with the installation (including facilities) expected to be used, and under the conditions expected to be used.

3.5.2 *Carrier Beat* (*Fork Beat*)

The beat is due to an undesired pick-up in the signal amplifier circuits of signal from the local frequency standard or motor amplifier circuits. In some cases, the nominal frequency of the synchronous motor is the same as that of the incoming carrier frequency. Since the difference in frequency is small and relatively constant, a regular pattern will be seen. This will ordinarily show as a variation in density at a slow rate and very nearly parallel to the recording line. The amount of undesired signal which can be tolerated depends upon the user's criterion for evaluation and upon the type of recording material used. The effect is most easily seen on photographic recordings in which the undesired signal may have to be 40 dB or more below maximum desired signal level to be unobjectionable.

BASIC TEST: A test which has been used for analysis follows:

A steady frequency which is about ½ cycle per second different from the frequency standard in the recorder is fed into the equipment at a level starting 30 dB below that required for the maximum signal when the sensitivity of the recorder is maximum. Tests are run by varying the level, to determine the measured peak-to-peak swing of the root-mean-square amplitude of the test frequency in the recording amplifier as related to the appearance of the pattern on the recorded copy. Once the acceptable performance in the recorded copy is agreed upon, the tests can be run by noting only the peak-to-peak swing of the amplitude.

APPENDIX

The 1964 IEEE Facsimile Test Chart and its various numbered patterns are frequently referred to in the text. For convenience a reproduction of this chart, and a diagram of the pattern numbers, are presented herewith. Pattern No. 6, which had been included in previous editions, was dropped from the 1964 issue.

FIGURE 28

Approved For Release 2001/09/05 : CIA-RDP80B00829A001100050001-1

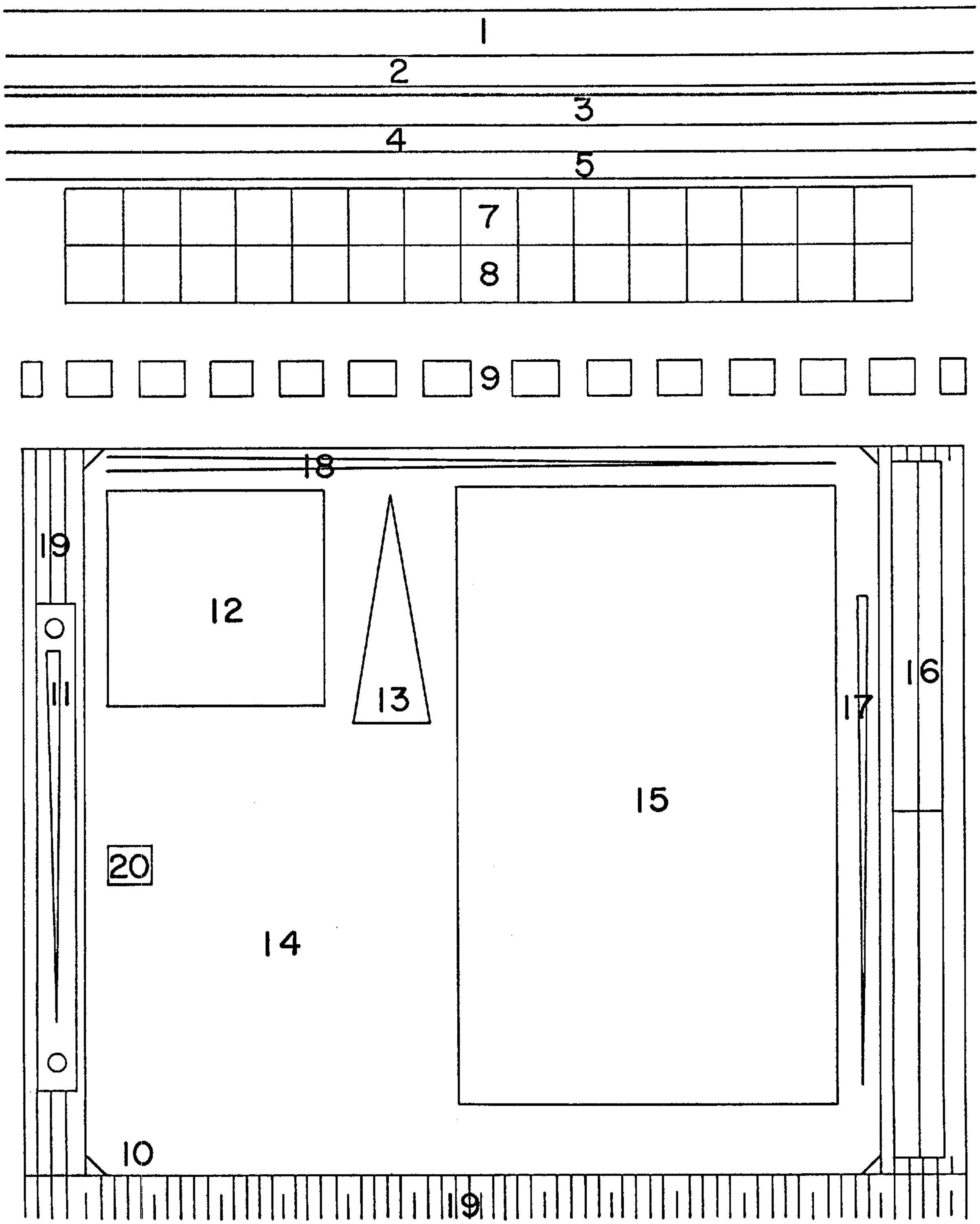


FIGURE 29

Approved For Release 2001/09/05 : CIA-RDP80B00829A001100050001-1

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